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| (54) Title: METHOD AND PRODUCT FOR THE SEQUENCE DETERMINATION OF PEPTIDES USING A MASS SPECTROMETER (57) Abstract Method is described for sequencing polypeptides by forming peptide ladders comprising a series of polypeptides in which adjacent members of the series vary by one amino acid residue and determining the identity and position of each amino acid in the polypeptide by mass spectroscopy. | | |

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METHOD AND PRODUCT FOR THE SEQUENCE DETERMINATION
OF PEPTIDES USING A MASS SPECTROMETER

RELATED APPLICATION

5 This application is a continuation in part of
copingending and commonly owned application serial number
07/891,177 filed May 29, 1992.

FIELD OF THE INVENTION

10 This invention relates to rapid and efficient
methods for sequencing formed or forming polypeptides
utilizing a mass spectrometer.

15 Polypeptides are a class of compounds composed of
 α -amino acid residues chemically bonded together by amide
linkages with elimination of water between the carboxy
group of one amino acid and the amino group of another
amino acid. A polypeptide is thus a polymer of α -amino
acid residues which may contain a large number of such
residues. Peptides are similar to polypeptides, except
that they are comprised of a lesser number of α -amino
20 acids. There is no clear-cut distinction between
polypeptides and peptides. For convenience, in this
disclosure and claims, the term "polypeptide" will be
used to refer generally to peptides and polypeptides.

Proteins are polypeptide chains folded into a defined three dimensional structure. They are complex high polymers containing carbon, hydrogen, nitrogen, and sulfur and are comprised of linear chains of amino acids connected by peptide links. They are similar to polypeptides, but of a much higher molecular weight.

For a complete understanding of physiological reactions involving proteins it is often necessary to understand their structure. There are a number of facets to the structure of proteins. These are the primary structure which is concerned with amino acid sequence in the protein chain and the secondary, tertiary and quaternary structures which generally relate to the three dimensional configuration of proteins. This invention is concerned with sequencing polypeptides to assist in determining the primary structure of proteins. It provides a facile and accurate procedure for sequencing polypeptides. It is also applicable to sequencing the amino acid residues at the termini of proteins.

Many procedures have been used over the years to determine the amino acid sequence, i.e. the primary structure, of polypeptides and proteins. At the present time, the best method available for such determinations

is the Edman degradation. In this procedure, one amino terminal amino acid residue at a time is removed from a polypeptide to be analyzed. That amino acid is normally identified by reverse phase high performance liquid chromatography (HPLC), but recently mass spectrometric procedures have been described for this purpose (1).

The Edman degradation cycle is repeated for each successive terminal amino acid residue until the complete polypeptide has been degraded. The procedure is tedious and time consuming. Each sequential removal of a terminal amino acid requires 20 to 30 minutes.

Hence, with a polypeptide of even moderate length, say for example 50 amino acid residues, a sequence determination may require many hours. The procedure has been automated. The automated machines are available as sequenators, but it still requires an unacceptable amount of time to carry out a sequence analysis.

Although the procedure is widely employed, one which required less time and which yielded information about a broader range of modified or unusual amino acid residues present in a polypeptide would be very useful to the art. A process which can be used to sequence individual members of mixtures of polypeptides would be particularly useful.

Recent advances in the art of mass spectroscopy have made it possible to obtain characterizing data from extremely small amounts of polypeptide samples. It is, for example, presently possible because of the sensitivity and precision of available instruments to obtain useful data utilizing from picomole to subpicomole amounts of products to be analyzed. Further, the incipient ion-trap technologies promise even better sensitivities, and have already been demonstrated to yield useful spectra in the 10^{-15} to 10^{-16} sample range.

In general, both electrospray and matrix-assisted laser desorption ionization methods mainly generate intact molecular ions. The resolution of the electrospray quadrupole instruments is about 1 in 2,000 and that of the laser desorption time-of-flight instruments about 1 in 400. Both techniques give mass accuracies of about 1 in 10-20,000 (i.e. +/- 0.01% or better). There are proposed modifications of time-of-flight analyzer that may improve the resolution by up to factor of 10-fold, and markedly improve the sensitivity of that technique.

These techniques yield mass measurements accurate to ± 0.2 atomic mass units, or better. These capabilities mean that, by employing the process of this invention, the polypeptide itself whether already formed or as it is being formed can be sequenced more readily, with greater speed, sensitivity, and precision, than the amino acid derivative released by stepwise degradation techniques such as the Edman degradation. As will be explained in more detail below, the process of this invention employs a novel technique of sequence determination in which a mixture containing a family of "fragments", each differing by a single amino acid residue is produced and thereafter analyzed by mass spectroscopy.

SUMMARY OF THE INVENTION

This invention provides a method for the sequential analysis of polypeptides which may be already formed or are being formed by producing under controlled conditions, from the formed polypeptide or from the segments of the polypeptide as it is being formed, a mixture containing a series of adjacent polypeptides in which each member of the series differs from the next adjacent member by one amino acid residue. The mixture is then subjected to mass spectrometric analysis to generate a spectrum in which the peaks represent the

separate members of the series. The differences in molecular mass between such adjacent members coupled with the position of the peaks in the spectrum for such adjacent members is indicative of the identity of the said amino acid residue and of its position in the chain of the formed or forming polypeptide.

The process of this invention which utilizes controlled cycling of reaction conditions to produce peptide ladders of predictable structure is to be contrasted with previous methods employing mass spectroscopy including exopeptidase digestion on uncontrolled chemical degradation. See references 2-5. Because of the uncontrolled nature of these previous methods, only incomplete sequence information could be obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 indicates a family or mixture of polypeptides (peptide ladder, as defined hereinafter) derived from a single formed polypeptide containing n amino acid residues. The mixture is analyzed in accordance with this invention to determine the amino acid sequence of the original polypeptide. Each amino

acid in the sequence is denoted by a number with the numbering starting at the amino terminal of the peptide. X denotes a terminating group.

Fig. 2 is an idealized mass spectrum of the peptide ladder of a polypeptide similar to the family shown in Fig. 1.

Fig. 3 shows the reactions involved in generating a peptide ladder from a formed polypeptide for analysis utilizing phenyl isothiocyanate (PITC) as the coupling reagent and phenyl isocyanate (PIC) as the terminating reagent.

Fig. 4 is a more precise summary of the process shown in Fig. 3.

Fig. 5 is an idealized mass spectrum of peptide ladders obtained from a mixture of two formed polypeptides one of which is identified as A, the other as B.

Fig. 6 is a positive ion, matrix assisted laser desorption mass spectrum of the formed polypeptide [Glu¹]fibrinopeptide B.

Fig. 7 is a positive ion matrix assisted laser desorption spectrum of [Glu¹]fibrinopeptide B after 7 cycles of sequential reactions in accordance with an embodiment this invention in which a formed polypeptide is degraded in a controlled manner to produce a mixture containing a peptide ladder.

Fig. 8 is the spectrum of the peptide ladder in the region 87-67 obtained from the mixture 99-67 in Example 2.

Fig. 9 is the spectrum of the mixture 66-33 obtained in Example 2.

Fig. 10 is a spectrum of the low mass region obtained from the mixture 66-33 obtained in Example 2 showing the side reaction products formed during the synthesis of HIV-1 protease.

Fig. 11 is a spectrum of the reaction mixture obtained in Example 3.

Figs. 12A and 12B show the reaction support system employed in an embodiment of the inventions which permits multiple simultaneous sequencing of polypeptides.

Figs. 13A and 13B are the mass spectra of the peptide ladders formed from both phosphorylated (12A) and unphosphorylated (12B) 16 residue peptides containing a serine residue.

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Fig. 14 shows the spectrum of a protein ladder generated by incomplete Edman degradation.

Fig. 15 shows the spectrum of the mixture obtained in Example 4.

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As will be explained in more detail below, Figs. 8 through 10 are spectra obtained in the sequencing of a forming polypeptide employing the process of this invention.

15

The invention will be more easily understood if certain of the terms used in this specification and claims are defined.

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The term "polypeptide" is used herein in a generic sense to describe both high and low molecular weight products comprising linear covalent polymers of amino acid residues. As the description of this invention proceeds, it will be seen that mixtures are produced which may contain individual components containing 100

or more amino acid residues or as few as one or two such residues. Conventionally, such low molecular weight products would be referred to as amino acids, dipeptides, tripeptides, etc. However, for convenience herein, all such products will be referred to as polypeptides since the mixtures which are prepared for mass spectrometric analysis contain such components together with products of sufficiently high molecular weight to be conventionally identified as polypeptides.

The term "formed polypeptide" refers to an existing polypeptide which is to be sequenced. It refers, for example to [Glu¹]fibrinopeptide B which is sequenced for purposes of illustration in Example 1. The process of the invention is, of course, most useful for sequencing the primary structure of unknown polypeptides isolated, for example, by reverse phase HPLC of an enzymatic digest from a protein.

The term "forming polypeptide" refers to such polypeptides as they are being formed for example by solid phase synthesis as illustrated in Example 2.

The term "peptide ladder" refers to a mixture containing a series of polypeptides produced by the processes described herein either from a formed or a

forming polypeptide. As will be seen from the various figures and understood from this description of the invention, a peptide ladder comprises a mixture of polypeptides in which the various components of the mixture differ from the next adjacent member of the series by the molecular mass of one amino acid residue.

A "coupling reagent" is a reactant which forms a reaction product with a terminal amino acid residue of a polypeptide to be sequenced and is subsequently removed together with the residue.

A "terminating reagent" is a reactant which similarly forms a reaction product with a terminal amino acid of polypeptide and is stable to subsequent cycling procedures.

DETAILED DESCRIPTION OF THE INVENTION

There are several procedures for building peptide ladders, some applicable to the sequencing of formed polypeptides, others to sequencing of polypeptides as they are being formed.

One such process will be understood from a study of Fig. 3 which shows an embodiment of the invention which is applicable to formed polypeptides. The figure shows

the sequencing of an original formed polypeptide which may contain any number of amino acid residues, even as many as 50 or more. The polypeptide is shown here by way of illustration as containing three residues, each residue with a side chain represented by R_1 , R_2 or R_3 in accordance with conventional practice.

The significant feature of this embodiment of the invention, as illustrated in the figure, is that the reaction conditions are cycled to produce a peptide ladder in the final mixture. The final mixture is analyzed by mass spectroscopy to determine the exact mass of the components of the ladder, thereby to accumulate the information necessary to sequence the original polypeptide.

The skilled artisan will recognize that this procedure of sequencing a formed polypeptide makes use of degradation chemistry, but is based on a new principle, i.e. the original polypeptide is employed to generate a family of fragments, each differing by a single amino acid as shown in Fig. 1 wherein X represents a terminating agent. Typically X will be a terminating agent that is resistant to all subsequent reactions or manipulations in the cyclic degradation

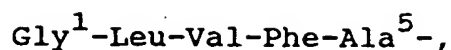
process of this invention. As will be described below, in connection with another embodiment of this invention, X may also be hydrogen.

In the process illustrated in Fig. 3, PITC is the coupling reagent and PIC is the terminating reagent. From such a family or peptide ladder of terminated molecular species prepared as outlined in the figure, the amino acid sequence can be simply read out in a single mass spectrometry operation, based on the mass differences between the intact molecular ions. Furthermore, because of the sensitivity of modern mass spectrometers, the accuracy of the amino acid sequence thus determined is unaffected, over a wide range (5-fold or more), by the amount of each molecular species present in the mixture.

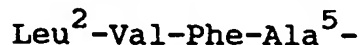
Fig. 2 shows an idealized mass spectrum of a peptide ladder in which each peak is representative of one member of a series of terminated polypeptides each member of which differs from the adjacent member by one amino acid residue.

Thus, for example, if the peaks of the highest mass in Fig. 2 represent a polypeptide, the first five members of which at the amino terminal end may be:

14



the next peak of lower mass would represent



5 Subsequent peaks would represent products with one less amino acid residue. The difference in mass between adjacent members of the series would be indicative of the amino acid residue removed. The difference in molecular mass between the first product on the right and the adjacent product would correspond to a glycine residue. Subsequent peaks show the sequential removal of leucine, valine, phenylalanine and alanine residues thus establishing the sequence of these amino acid residues in the original polypeptide.

15 Fig. 3 illustrates a practical sequence of reactions by which the idealized procedure of Figs. 1 and 2 can be conducted utilizing PITC and PIC as the reagents for sequencing an original formed polypeptide by cycling reaction conditions to produce a peptide ladder for spectrometric analysis.

20 In the first step of the sequencing procedure the original polypeptide is reacted with a mixture of PITC and PIC under basic conditions. A large molar excess of each reagent is employed. A much larger amount of PITC than of PIC is utilized so as to be certain that at each

cycle of the procedure most of the available polypeptide reacts with the coupling agent but that a small measurable fraction of the available peptide reacts with the terminating reagent. The fraction reacted with the terminating agent will be determined by the relative activities of the coupling agent and the terminating agent, and the molar ratio of the two reagents.

The first reaction products which form during the basic step of the cycle comprise a mixture of original polypeptide terminated with PIC (PC-polypeptide) and an original polypeptide terminated with PITC (PTC-polypeptide). The PIC terminated polypeptide (PC-polypeptide) is stable or essentially stable under all subsequent reaction conditions with the result that it will be present in a measureable amount in the final mixture when that mixture is ready for analysis.

The next step in the procedure is to subject the PTC-polypeptide/PC-polypeptide mixture to acid conditions whereupon a reaction product separates from the PTC-polypeptide. This reaction product contains the terminal amino acid residue of the original peptide. The separation of this product results in the formation

of a new polypeptide which, because the terminal amino acid has been cleaved contains one less amino acid than the original polypeptide.

The reaction mixture formed at the end of this cycle contains as the principal products:

1. unreacted coupling and terminating reagents,
2. a first reaction product which is the reaction product between the original polypeptide and the terminating reagent. It is a PC terminated polypeptide (PC-polypeptide).
3. a new polypeptide from which the amino terminal amino acid residue has been removed.

The skilled artisan will readily understand that sequential repeats of the cycle just described will result in the formation of a mixture which contains as the principal measureable components a series of PC-polypeptides each member of which contains one less amino acid residue than the next higher member of the series. The member of the series with the highest molecular mass will be the first reaction product between the original polypeptide and the terminating

reagent. The molecular mass of each subsequent reaction product in the series will be the molecular mass of the next higher adjacent member of the series minus the molecular mass of the terminal amino acid residue removed by reaction with the PITC. The molecular mass of the PIC, blocking group or any other blocking group selected is irrelevant to the spectrometric analysis since the identity of each amino acid residue removed from the next adjacent peptide is determined by differences in molecular mass. These differences identify the amino acid residue, and the position of that mass difference in the spectrum data set defines the position of the identified residue in the original polypeptide.

A constant 5% termination of the available polypeptide at each cycle for ten cycles of the described chemistry would yield a peptide ladder in which the mole fraction of the original polypeptide after each cycle would be approximately

| | | MOLE |
|----|---|------|
| 20 | FRACTION | |
| | (X)-1-2-3-4-5-6-7-8-9-10-11-12-.....-n-(OH) | .050 |
| | (X)-2-3-4-5-6-7-8-9-10-11-12-.....-n-(OH) | .048 |
| | (X)-3-4-5-6-7-8-9-10-11-12-.....-n-(OH) | .045 |
| 25 | (X)-4-5-6-7-8-9-10-11-12-.....-n-(OH) | .043 |
| | (X)-5-6-7-8-9-10-11-12-.....-n-(OH) | .041 |
| | (X)-6-7-8-9-10-11-12-.....-n-(OH) | .039 |
| | (X)-7-8-9-10-11-12-.....-n-(OH) | .037 |
| | (X)-8-9-10-11-12-.....-n-(OH) | .035 |

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| | |
|-----------------------------|---------|
| (X)-9-10-11-12-.....-n-(OH) | .033 |
| (X)-10-11-12-.....-n-(OH) | .031 |
| (X)-11-12-.....-n-(OH) | .60 |
| | remains |

5 The differences in molecular mass between each successive member of the series in the peptide ladder can be readily determined with high precision by mass spectroscopy.

10 With relatively low molecular weight polypeptides, it is possible to repeat each cycle without removal of unreacted PITC or PIC. However, as illustrated in Example 1, it is generally preferred to remove unreacted coupling and terminating reagents at the completion of each cycle. Such removal may also include removal of
15 the cleavage reaction product between the coupling reagent and the terminal amino acid.

20 Fig. 4 is a more precise summary of the procedure illustrated in Fig. 3 and described in detail above. It specifically illustrates the process utilizing a "one pot" technique. In the figure "AA" stands for amino acid and ATZ represents 5-anilinothiazolinone. The other symbols have the same meaning as above.

The figure illustrates the preparation of a peptide ladder from a formed polypeptide using controlled ladder-generating chemistry. The stepwise degradation is conducted with a small amount of PIC and a major proportion of PITC. Successive cycles of peptide ladder generating chemistry are performed as described above without intermediate isolation or analysis of released amino acid derivatives. Finally the mixture containing the peptide ladder is read out in one step by laser desorption time-of-flight mass spectrometry (LDMS).

The coupling and terminating reagents are not limited to the pair described above. Those skilled in the art can readily select other equivalent reagents. Of course, the procedure can be adapted to either the amino terminal or the carboxy terminal of the polypeptide under analysis.

Another procedure for constructing a peptide ladder from a formed polypeptide is to conduct each cycle in a manner to insure incomplete termination. The process is similar to the above described procedure except that only a coupling reagent is employed and the peptide ladder comprises a series of polypeptides none of which is terminated with a terminating reagent but each of which differs from the adjacent member of the series by

one amino acid residue. In this procedure, X of Fig. 1 is hydrogen. The principle of this embodiment of the invention is that only the coupling reagent is employed in the cycle, and the extent of reaction is limited for example by limiting reaction times so that all of the original formed polypeptide does not react. As a result, after the cycle has been moved to the acid step, the reaction mixture produced will contain:

1. Unreacted PITC,
2. The reaction product of PITC and the terminal amino acid residue with which it has reacted (PTC-polypeptide),
3. Unreacted original formed polypeptide,
4. A polypeptide with one less amino acid residue than the original polypeptide.

It will be apparent that by suitable adjustment of reaction conditions, continued repetition of the cycle any selected number of times will produce a desired peptide ladder similar to the ladder produced in the procedure which employs both coupling and terminating reagents except that the polypeptide members of the ladder are not end blocked with a terminating reagent. This process is similarly applicable to a mixture of polypeptides.

Another procedure for generating a peptide ladder with only one reagent involves termination by side reaction. In one such process, PITC is employed as a coupling reagent; and, under controlled conditions of oxidation, a small amount of PITC terminated polypeptide is converted to stable PIC terminated peptide to form a peptide ladder after a selected number of cycles. The key to this aspect of the invention is the controlled oxidation of a small amount of the PITC terminated polypeptide to form PIC terminated polypeptide which is stable, or essentially stable, under subsequent reactions conditions.

To describe the process with more specificity, the reaction steps are as follows:

1. React the polypeptide to be sequenced under basic conditions with an excess of PITC to convert substantially all of the polypeptide to PITC terminated polypeptide (PTC-polypeptide).

2. React the PTC-polypeptide with a controlled amount of oxygen to convert a small portion of the PTC-polypeptide, say 5%, to PC-polypeptide while leaving the balance unchanged.

3. Cycle the mixture to the acid step to cleave the PITC bound terminal amino acid from the PTC-polypeptide and leave a polypeptide with one less amino acid residue than the original polypeptide.

4. Repeat the cycle any selected number of times to generate a peptide ladder for mass spectrometric analysis.

A very significant practical advantage of the process of this invention is that it is possible to sequence a plurality of peptides in one reaction system. This advantage arises principally from the high degree of accuracy that is possible because of the recent advances in mass spectroscopy.

This aspect of the invention will be understood by reference to Figs. 12A and 12B which show a suitable device for producing a plurality of peptide ladders. In the figure, 1 is a reaction support member shown in the form of a cylinder with a holding basin 2 and a through bore 3 permitting the passage of chemicals. A series of absorbent members or discs 4, for example absorbent

membranes are supported by a thin filter member 5 which may be simply a glass fiber or other suitable filter material.

In practice, the support member would be in a closed system adapted to permit the appropriate reactants for the preparation of a peptide ladder on each disc to contact each polypeptide to be sequenced. After each step of the cycle, the reactants exit the support member through the bore 3. The reactants are delivered to the reaction zone by any conventional pumping system of the type employed to collect reactants from a series of reservoirs, mix them and pass the mixture through a delivery nozzle.

Sequencing of formed polypeptides on samples immobilized on a solid support, as in the this embodiment of the invention is especially advantageous because it is applicable to very small amounts of total sample and because there are reduced handling losses and increased recoveries.

As applied to the system illustrated in the figures, any convenient number of polypeptides to be sequenced are separately absorbed on separate discs 4 which may be, for example, an absorbent membrane such as

the cationic, hydrophilic, charge modified
polyvinylidene fluoride membrane available from
Millipore Corp. as Imobilon CD.

5 The discs are spaced apart on the filter paper 5
which is supported over the through bore 3 on support
member 1 which is then placed in a closed system to
conduct the controlled cyclic reactions appropriate to
the production of a peptide ladder in accordance with
this invention.

10 The amount of polypeptide absorbed on each segment
may be as small as one picomole or even less.
Generally, it is from about 1 to about 10 picomoles.

15 In a typical operation, 1 to 10 picomoles of each
polypeptide are separately absorbed on the selected
membrane discs and placed separately on the filter paper
which is then placed on the support member as shown. The
peptides are subjected to the PITC/PIC/base/acid cycle
described above to generate a peptide ladder on each
disc. Each separate peptide ladder containing mixture
20 to be analyzed may be extracted from each separate
membrane with an organic solvent containing a small

amount of surfactant. One useful extraction solvent is 2.5% trifluoroacetic acid in a 1:1 mixture of acetonitrile and 1-O-n-octyl- β -glucopyranoside.

Fig. 14 shows the spectrum obtained using the absorbent membrane technology coupled with incomplete termination described above. To generate the peptide ladder which was analyzed, 50 picomoles of [Glu-1] fibrinopeptide B on Immobilon-CD membrane was applied to ABI-471A protein sequencer (Applied Biosystem). The sequencer was programmed using 5.5 minute cycle time with a cartridge temperature of 56°C so as to insure incomplete reaction at each cycle. Six cycles were performed. Under these conditions, a reaction yield of about 56% was estimated. The resulting peptide ladder is comprised of free N-terminal amines.

This example illustrates the speed with which the sequencing can be performed. Similar spectra were obtained with a total loading of only 1 picomole of polypeptide on the membrane.

Although this multiple, simultaneous, sequence analysis of separate formed polypeptides utilizing the same chemical reagents for separate reactions with the said polypeptides has been specifically described by

reference to the use of a mixture of specific coupling and terminating reagents in the same reaction zone, it will be apparent that the process is equally applicable to the other processes described above.

5 The system is, of course, applicable to the use of only one disc for the sequencing of a polypeptide or polypeptide mixture.

10 Although the discs are shown separately on the support, they may also be stacked or replaced with a column of suitably absorbent packing materials.

15 Further, there may be a number of support members in one device and the chemicals fed to the separate support members through a manifold system so that instead of only one reaction zone, there may be a plurality of reaction zones to still further increase the number of polypeptides which can be simultaneously sequenced.

20 An especially important embodiment of this invention is that it provides a method of locating covalent modifications on a polypeptide chain particularly post translational modifications of biologically important products which on chemical or

enzymatic hydrolysis produce polypeptides which are phosphorylated, acetylated, glycosylated, cross-linked by disulfide bonds or otherwise modified. Such polypeptides are referred to in this specification and claims as "modified polypeptides".

The inability to directly identify, locate, and quantify modified amino acid residues such as phosphorylated residues in a modified polypeptide is a major shortcoming of standard sequencing methods, and has imposed major limitations on currently important areas of biological research, such as mechanisms of signal transduction. The process of this invention has general application to the direct identification of post-translation modifications present in a peptide chain being sequenced. A modified amino acid residue that is stable to the conditions used in generating the peptide ladder from a formed peptide reveals itself as an additional mass difference at the site of the covalent modification. As described above, from the mass difference, both the position in the amino acid sequence and the mass of the modified amino acid can be determined. The data generated can provide unambiguous identification of the chemical nature of the post translational modification.

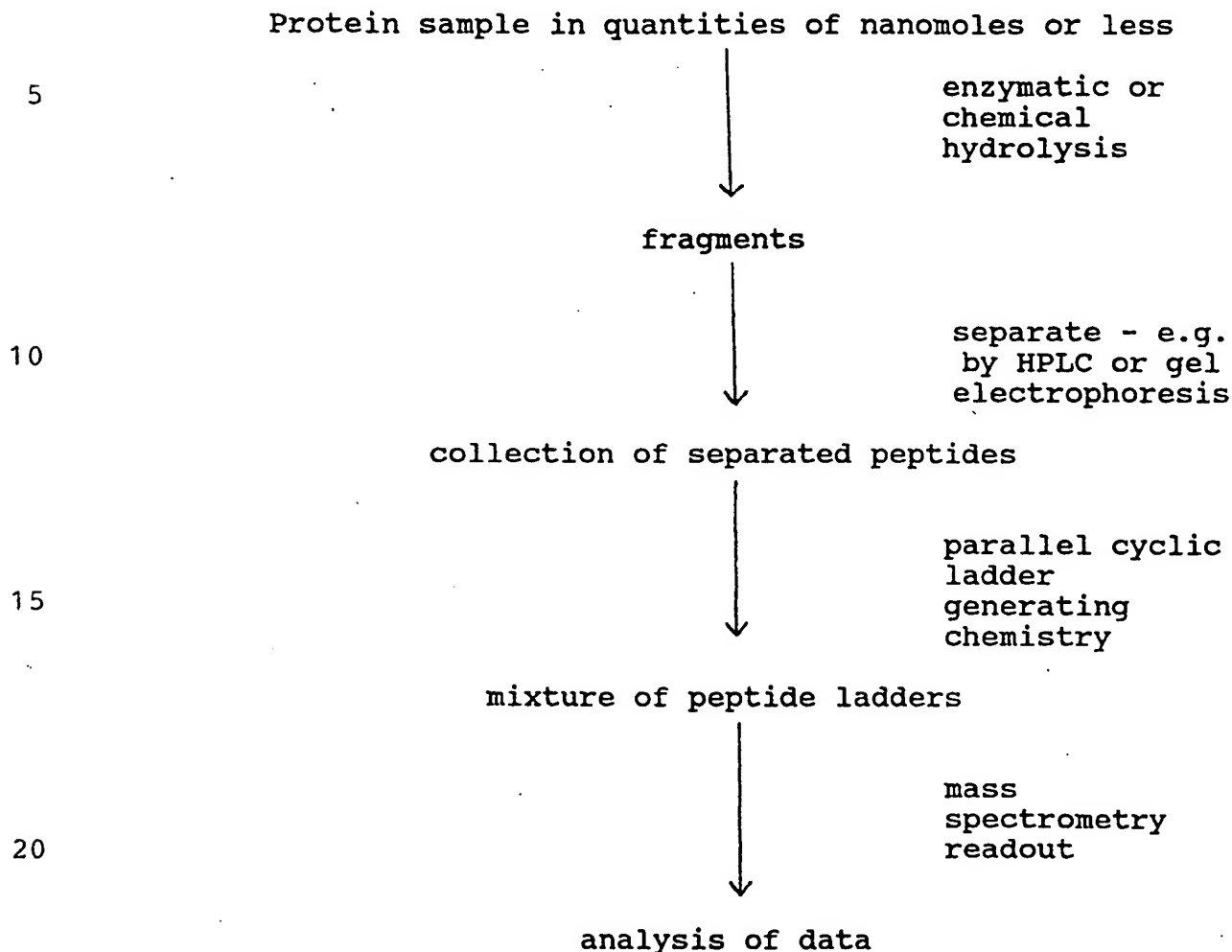
A typical example of this aspect of the invention is the analysis of both phosphorylated and unphosphorylated forms of the 16 residue peptide LRRASGLIYNNTLMAR amide prepared by the method of Schnolzer et al (9) containing a phosphorylated serine residue prepared by enzymatic reaction using 3', 5'-cyclic AMP-dependent kinase. After ten cycles of PITC/PIC chemistry on each form of the peptide using the procedures described above and illustrated in Example 1, the two separate sequence-defining fragment mixtures (peptide ladders) were each read out by laser desorption mass spectrometry. The resulting protein ladder data sets are shown in Figs. 13A and 13B. Again, the mass differences define the identity and order of the amino acids. For the phosphopeptide (Fig. 13A), a mass difference of 166.7 daltons was observed for the fifth amino acid from the N-terminal, compared with the mass difference of 87.0 for the same residue in the unphosphorylated peptide (Fig. 13B). This measured mass difference corresponds to a phosphorylated serine residue, calculated mass 167.1 daltons. Thus, the protein ladder sequencing method has directly identified and located a Ser(Pi) at position five in the peptide. There was no detectable loss of phosphate from the

phosphoserine residue, which has been regarded in the art as the most sensitive and unstable of the phosphorylated amino acids.

Although only ten cycles of ladder generating chemistry were performed, sequence-defining fragments corresponding to eleven residues were observed, apparently arising from a small amount of premature cleavage (10). This side reaction which can have serious consequences for standard Edman methods, has no effect on the ladder sequencing approach.

A specific and very important advantage of this invention is that it is not limited to analysis of one polypeptide. Mixtures of polypeptides can be analyzed simultaneously in one reaction vessel. Each polypeptide will give a separate spectrum as shown in idealized form in Fig. 4. In this figure, the molecular masses of the original components of the mixture differ by any arbitrary mass difference. Each of the separate spectra can be analyzed as described above even though there may be appreciable overlapping in molecular mass among the polypeptides to be sequenced. This will be clear from the figure. As a result, it is possible to sequence

proteins by analyzing mixtures of polypeptides obtained by chemical or enzymatic hydrolysis of the protein. The process can be outlined as follows:



In most cases, gel electrophoresis will be employed to separate proteins and HPLC to separate polypeptides. Thus, for example, a protein mixture can be separated into its protein components by electrophoresis and each separate component sequenced by digestion into polypeptides, separation and ladder sequencing in

accordance with the process of this invention to yield data from which the sequence of the entire protein can be deduced. The process of the invention may also be employed to obtain extensive data relating to the primary structure of intact proteins at their amino or carboxy terminals.

There follows a description of the application of this invention to a forming peptide.

Stepwise solid phase peptide synthesis involves the assembly of a protected peptide chain by repetition of a series of chemical steps (the "synthetic cycle") which results in the addition of one amino acid residue to an amino acid or peptide chain bound to a support, usually a resin such as methylbenzhydrylamine. The final polypeptide chain is built up one residue at a time, usually from the C-terminal, by repetition of the synthetic cycle. As is well known to peptide chemists, the solid phase synthetic method does not always proceed according to plan. For any of a number of reasons, some of the polypeptide formed may terminate before the final product is produced. For example, a synthesis designed to produce a polypeptide containing twenty amino acid residues may produce as side products a variety of

polypeptides containing lesser numbers of amino acid residues, e.g. tripeptides, octapeptides and dodecapeptides.

5 To utilize the advantages of this invention in solid phase synthesis, polypeptide-resin samples are collected after each cycle of amino acid addition. Mixing approximately equal amounts of all samples obtained in the course of a synthesis yields a peptide ladder containing all possible lengths of resin bound
10 polypeptide. Cleavage of the resin from such a mixture produces a mixture of free polypeptide chains of all possible lengths containing a common carboxy or amino terminal. Usually, stepwise solid phase synthesis proceeds starting from the carboxy terminal. In these
15 cases, the resulting peptide ladder will contain polypeptides all having a common carboxy terminal.

Consideration of the steps involved in the production of a heptapeptide will explain the procedure. If the heptapeptide to be produced is of the structure:

20 Ala¹-Val-Gly-Leu-Phe-Ala-Gly⁷,

the first synthetic step is the attachment of Gly to the resin, usually with a spacer molecule between the resin and the Gly. The next step is the attachment of N^α-blocked Ala to the Gly following well known, coupling

and deblocking procedures so that the synthesis is controlled. The cycle is repeated to form the heptapeptide on the resin from which it may be isolated by standard methods.

5 In accordance with the procedure of this invention, a small sample of polypeptide attached to resin is removed after each cycle. After completion of the synthesis, the seven samples are added together to produce a peptide ladder which contains the following
10 components.

Gly-Resin

Ala-Gly-Resin

Phe-Ala-Gly-Resin

Leu-Phe-Ala-Gly-Resin

15 Gly-Leu-Phe-Ala-Gly-Resin

Val-Gly-Leu-Phe-Ala-Gly-Resin

Ala-Val-Gly-Leu-Phe-Ala-Gly-Resin

The mixture is then treated, for example with hydrogen fluoride to generate a resin-free peptide
20 ladder which is analyzed mass spectrometrically to assure that the final heptapeptide is of the desired amino acid structure.

One possible type of side reaction in stepwise solid phase synthesis is low level blocking at a particular residue (step) in the synthesis.

It will be apparent that each has occurred and mixed separate sample collected subsequent to the step at which a side reaction such as low level blocking has occurred above during the assembly of the final polypeptide will contain a portion of such terminated side product with the result that the amount of such terminated peptide is amplified in the final mixture as prepared for mass spectrometric analysis. Thus, for example, if for some reason such as low level blocking there was a termination of some polypeptide at the decapeptide stage in a synthesis designed to produce a 20-residue polypeptide, the sample from each subsequent synthetic cycle would contain terminated decapeptide and the final analytical sample would contain a 10-fold amplification of this side product. The information obtained by this method of analysis is very useful in designing optimum procedures for synthesizing polypeptides, especially those of high molecular weight. One adaptation of this invention to solid phase synthesis is illustrated in Example 2.

Optionally, the peptide resin samples collected as described above may be assayed colorimetrically, for example by a ninhydrin procedure to determine reaction yields prior to mixing to form a peptide ladder. This procedure provides a complimentary method of controlling and assessing the process.

In the foregoing process, a sample of polypeptide attached to the resin is collected at each step of the synthetic cycle for the preparation of the final analytical mixture. An alternative procedure for preparing the final sample is deliberate termination of a small portion of the forming peptide at each step of the synthetic cycle followed by removal of all of the peptides from the resin to form the analytical mixture directly.

This can be accomplished by utilizing, instead of one reversibly blocked amino acid residue at each step in the cycle, a mixture of the selected amino acid residue one portion of which is stable under the reaction conditions, another portion of which is susceptible to removal of the blocking group under controlled conditions.

If, for example, the amino acid residue to be added to the forming polypeptide is alanine, the peptide bond could be formed utilizing a mixture of Boc-alanine and Fmoc-alanine in which the carboxyl group is in the appropriate form for reaction, for example in the form of an hydroxybenzotriazole ester. After the peptide bond has been formed, one of the blocking groups, the removable group, can be removed under conditions such that the other blocking group remains intact.

Repetition of this cycle will result in the formation of the desired polypeptide on the resin together with a peptide ladder comprising a series of polypeptides each member of which is joined to the resin and is terminated by the selected blocking group.

The procedure will be more readily understood by reference to the preparation of a specific polypeptide such as:



The chemistry involved in the preparation of such pentapeptide is standard solid phase polypeptide synthesis applied in such a manner as to produce a peptide ladder. As applied to this invention, by way of example, the C-terminal amino acid residue would be

joined to the resin, typically through a linker, as a mixture containing a major proportion of t-Boc-isoleucine and a minor proportion of Fmoc-isoleucine, e.g. in a 19:1 ratio.

5 The t-Boc blocking group is next removed with an acid such as trifluoroacetic acid. Since the Fmoc group is stable under acid conditions the Fmoc-isoleucine attached to the resin will retain its blocking group and will be stable to all subsequent reactions.

10 In the next step of this synthesis, a 19:1 mixture of Boc-leucine and Fmoc-leucine will be joined to the Ile-Resin, and the Boc blocking group selectively removed under acid conditions. As a result of this step in the synthetic cycle, the state of the resin may be
15 indicated by:

Fmoc-Ile-Resin

Fmoc-Leu-Ile-Resin

Leu-Ile-Resin

20 Repetition of these reactions will result in a final resin mixture comprising a peptide ladder which may be represented by:

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Fmoc-Ile-Resin

Fmoc-Leu-Ile-Resin

Fmoc-Ala-Leu-Ile-Resin

Fmoc-Phe-Ala-Leu-Ile-Resin

5 Fmoc-Gly-Phe-Ala-Leu-Ile-Resin

Gly-Phe-Ala-Leu-Ile-Resin

10 This peptide mixture is removed from the resin by standard solid phase procedures which, optionally, will also remove the Fmoc group to produce an analytical sample ready for analysis by mass spectroscopy as described above.

The peptide ladder can also be formed by the reverse procedure of employing Fmoc as the removable group and t-Boc as the terminating group.

15 The adaptation of this invention to solid phase synthesis techniques is illustrated in Example 3 and Fig. 11

20 Any blocking group stable to the conditions of chain assembly synthesis can be used in this application of the invention. For example, acetic acid could be added to each reversibly N-protected amino acid in a

stepwise solid phase synthesis in an amount suitable to cause a few percent permanent blocking of the growing peptide chain at each step of the synthesis. The mass of the blocking group is without effect on the ability to read out the sequence of the peptide synthesized since the readout relies on mass differences between adjacent members of the polypeptide series as described above.

Using the procedures described, each individual resin bead carries the mixture of target full-length peptide and the peptide ladder. Typically each bead carries from 1 to 10 or more picomoles of polypeptides. Thus, cleavage of the products from a single bead permits the direct determination of the sequence of the polypeptide on that bead.

It is recognized that the foregoing procedures are described in an idealized form which does not include possible interference by other functional groups such as the hydroxyl group in tyrosine and serine, the "extra" carboxyl groups in dicarboxylic amino acids or the "extra" amino groups in dibasic amino acids. This method of description has been adopted to avoid unnecessarily lengthening the specification. The artisan will recognize the problems which will be

introduced by the other functional groups and will know how to deal with them utilizing techniques well known to peptide chemists.

It will also be recognized that the procedures described have been applied to relatively small polypeptides. They are equally applicable to large polypeptides. For example, if the forming polypeptide is one which contains twenty or more amino acid residues, it may be expedient to sequence the pentapeptide, the decapeptide and the pentadecapeptide to be certain that the synthesis is going according to plan.

A variety of other chemical reaction systems can be employed to generate peptide ladders for analysis in accordance with this invention.

It will be recognized that there are a number of significant advantages to the processes of this invention. For example, the demands on yield of the chemical degradation reactions are much less stringent and more readily achieved than by wet chemical stepwise degradation techniques such as the Edman degradation in which low molecular weight derivatives are recovered and analyzed at each chemical step. Other advantages

include accuracy, speed, convenience, sample recovery,
and the ability to recognize modifications in the
peptide such as phosphorylation. Relatively
unsophisticated and inexpensive mass spectrometric
5 equipment, e.g. time of flight; single quadrupole; etc.
can be used.

By employing the process of this invention, it is
routinely possible to sequence polypeptides containing
10 or more amino acid residues from one picomole, or
10 even a smaller amount of a polypeptide in one hour or
less including cyclic degradation, mass spectrometry,
and interpretation.

The processes described may be readily automated
i.e., carried out for example in microtiter plates,
15 using an x, y, z chemical robot. Furthermore, the
determination of amino acid sequence from mass
spectrometric data obtained from the protein sequencing
ladders is readily carried out by simple computer
algorithms. The process of the invention therefore
20 includes computer read-out of the spectra of the peptide
ladders produced.

The skilled artisan will recognize that there are some limitations to the process of the invention as described above.

For example, some pairs of amino acids such as leucine and isoleucine have the same molecular weights. Therefore, they can not be distinguished by mass differences of terminated polypeptides in a series. There are several procedures for avoiding this difficulty. One is to differentiate them by CDNA sequencing. They are highly degenerate codons, so they can be accommodated by inosine substitution in DNA probes/primers for isolation/identification of the corresponding gene. This limitation will have little impact on practical application of the invention.

Further, several amino acids differ by only 1 amu. This places stringent requirements on accuracy of mass determination. However, this invention utilizes a determination of mass differences between adjacent peaks, not a determination of absolute masses. Since mass differences can be determined with great accuracy by mass spectroscopy, the limitation will also be of little practical significance.

Finally, samples which are blocked at the amino or carboxy terminal may not be susceptible to the generation of peptide ladders. This problem can be circumvented by chemical or enzymatic fragmentation of the blocked polypeptide chain to yield unblocked segments which can be separately analyzed.

The following non-limiting examples are given by way of illustration only and are not to be considered as limitations of the invention many apparent variations of which may be made without departing from the spirit or scope thereof.

Example 1

Sequencing of [Glu¹]Fibrinopeptide B

[Glu¹]Fibrinopeptide B was purchased from Sigma Chemical Co. (St. Louis, Mo.). The reported sequence was: Glu¹-Gly-Val-Asn-Asp⁵-Asn-Glu-Glu-Gly-Phe¹⁰-Phe-Ser-Ala-Arg¹⁴. Matrix assisted laser desorption mass spectrometry gave MW 1570.6 dalton (Calculated: 1570.8 dalton) and showed high purity of the starting peptide. A mixture of PITC plus 5% v/v phenylisocyanate PIC was used in the coupling step. PIC reacts with the NH₂- of a polypeptide chain to yield an N^α-phenylcarbonyl-peptide which is stable to the conditions of the Edman

degradation. A modification of a standard manual Edman degradation procedure (6) was used. All reactions were carried out in the same 0.5mL polypropylene microfuge tube under a blanket of dry nitrogen. Peptide (200pmoles to 10 nmole) was dissolved in 20ul of pyridine/water (1:1v/v; pH10.1); 20uL of coupling reagent containing PITC:PIC:pyridine:hexafluoroisopropanol (20:1:76:4 v/v) was added to the reaction vial. The coupling reaction was allowed to proceed at 50°C for 3 minutes. The coupling reagents and non-peptide coproducts were extracted by addition of 300uL of heptane:ethyl acetate (10:1v/v), gentle vortexing, followed by centrifugation to separate the phases. The upper phase was aspirated and discarded. This washing procedure was repeated once, followed by washing twice with heptane:ethyl acetate (2:1v/v). The remaining solution containing the peptide products was dried on a vacuum centrifuge. The cleavage step was carried out by addition of 20uL of anhydrous trifluoroacetic acid to the dry residue in the reaction vial and reaction at 50°C for 2 minutes, followed by drying on a vacuum centrifuge. Coupling-wash-cleavage steps were repeated for a predetermined number of cycles. The low MW ATZ/PTH derivatives released at each cycle were not separated/analyzed. Finally, the total product mixture was subjected to an

additional treatment with PIC to convert any remaining unblocked peptides to their phenylcarbamyl derivatives. In this final step, the sample was dissolved in 20uL of trimethylamine/water (25%wt/wt) in pyridine (1:1v/v);

5 20uL of PIC/pyridine/HFIP (1:76:4v/v) was added to the reaction vial. The coupling reaction was carried out at 50°C for 5 min. The reagents were extracted as described above. After the last cycle of ladder generating chemistry, the product mixture was dissolved

10 in 0.1% aqueous trifluoroacetic acid: acetonitrile (2:1, v/v). A 1uL aliquot (250pmol total peptide, assuming no losses) was mixed with 9uL of α -cyano-4-hydroxy-cinnammic acid (5g/L in 0.1% trifluoroacetic acid: acetonitrile, 2:1 v/v), and 1.0uL of this mixture of

15 total peptide products (25pmol) and matrix was applied to the probe tip and dried in a stream of air at room temperature. Mass spectra were acquired in positive ion mode using a laser desorption time-of-flight instrument constructed at The Rockefeller University (7). The

20 spectra resulting from 200 pulses at a wavelength of 355nm, 15 mJ per pulse, were acquired over 80 seconds and added to give a mass spectrum of the protein sequencing ladder shown in Fig. 7. Masses were calculated using matrix peaks of known mass as

25 calibrants.

Peptide sequence read-out. Positive ion (MALDMS) spectra of [Glu¹]Fibrinopeptide B is shown in Fig. 6. A protonated molecular ion [M+H] was observed at m/z 1572.5 (calculated value is 1571.8).

5 Its positive ion MALDMS spectrum of the reaction mixture obtained after seven cycles is shown in Fig. 6. Each of the peaks in the spectrum represents a related phenylcarbamoylpeptide derivative in the peptide ladder (except a few peaks which will discussed later). The
10 amino acid sequence can be easily read-out from the mass difference of adjacent two peaks. for instance, the mass difference are 129.1, 56.9, and 99.2 between peaks at m/z 1690.9 and 1561.8, peaks at m/z 1561.8 and 1504.9 and peaks at m/z 1504.9 and 1405.7. Which correspond to
15 glutamic acid (ca. 129.12), glycine (ca. 57.05) and valine (ca. 99.13) residues, respectively. One set of paired peaks gives mass difference 119.0 (1062.1-943.1) which corresponds to the phenylcarbamoyl group. In other words, these two peaks represent one piece of
20 peptide with or without phenylcarbamoyl group. Peak at m/z 1553.8 corresponds partially blocked peptide with pyroglutamic acid at the N-terminus. This results from cyclization of the N-terminal Glu under the reaction

conditions used. Such products are readily identified from the accurately measured mass and known chemical reaction tendencies.

Example 2

5 Stepwise solid phase synthesis of the 99 amino acid residue polypeptide chain corresponding to the monomer of the HIV-1 protease (SF2 isolate):

PQITLWQRPLVTIRIGGQLKEALLDTGADDTVLEEMNLPGKWKPKMIGGIGGFIKVR
QYDQIPVEI(Aba)GHKAIGTVLVGPTPVNIIGRNLLTQIG(Aba)TLNF⁹⁹

10 [where Aba = α -amino-n-butyric acid] was undertaken.

Highly optimized Boc-chemistry instrument-assisted stepwise assembly of the protected peptide chain was carried out on a resin support, according to the method described by S.B.H. Kent (8). Samples (3-8mg, about
15 1 μ mole each) were taken after each cycle of amino acid addition. The protected peptide-resin samples were mixed in three batches of consecutive samples: (number corresponds to the amino acid after which sample was taken, i.e. residue number in the target sequence.) '99-
20 67; 66-33; 32-1. The first such mixture contained the peptides:

48

99-Resin

98-99-Resin

97-98-99-Resin

96-97-98-99-Resin

5

. . . .(etc.). . . .

70. . . . 96-97-98-99-Resin

69-70. . . . 96-97-98-99-Resin

68-69-70. . . . 96-97-98-99-Resin

67-68-69-70. . . . 96-97-98-99-Resin

10

Similarly for the other two mixtures. The mixed batches of peptide-resin were deprotected and cleaved with HF (1 hours, at 0°C, plus 5% cresol/5%/thiocresol). The products were precipitated with diethyl ether, dissolved in acetic acid-water 950/50%, v/v) and then lyophilized.

15

Each peptide mixture was dissolved in 0.1% TFA, 1
uL of the peptide mixture (10 uM per peptide component)
was added to 9uL of 4-hydroxy- -cyanocinnamic acid in a
1:2 (v/v) ratio of 30% acetonitrile/0.1% aqueous
trifluoroacetic acid. 0.5uL of the resulting mixture
was applied to the mass spectrometer probe and inserted
into the instrument (7). The spectra shown in Figs. 8
and 9 are the result of adding the data of each of 100

20

laser shots performed at a rate of 2.5 laser shots/second. Figure 8 shows the mass spectrum obtained from the mixture resulting from cleaving mixed samples from residues 99-67 of the synthesis. Fig. 9 shows the mass spectrum obtained from the mixture resulting from cleaving mixed samples from residues 66-33 of the synthesis. Table 1 shows the measured mass differences between consecutive peaks of a selection of these peaks and compares them with the mass differences calculated from known sequences of the target peptides. The agreements are sufficiently close to allow confirmation of the correctness of the synthesis.

Figure 11 shows mass spectra of the mixture obtained from mixed samples from residues (66-33) of the synthesis.

The sequence of the assembled polypeptide chain can be read out in a straightforward fashion from the mass differences between consecutive peaks in the mass spectra of the peptide mixture. This confirmed the sequence of amino acids in the peptide chain actually synthesized. The identity of the amino acids as determined by such mass differences is shown in Table 1

Table 1. The identify of amino acid by the mass differences in protein ladder sequencing using matrix-assisted laser desorption mass spectrometry.

| | Amino Acid | Mass Difference (Measured, Da) | Deviation | Amino Acid | Mass Difference (Measured, Da) | Deviation |
|----|-------------------|--------------------------------|-----------|-------------------|--------------------------------|-----------|
| 5 | Leu ³³ | 113.3 | 0.1 | Asp ⁶⁰ | 114.8 | -0.3 |
| | Glu ³⁴ | 129.7 | 0.6 | Gln ⁶¹ | 128.7 | 0.6 |
| | Glu ³⁵ | 129.5 | 0.4 | Ile ⁶² | 113.2 | 0.0 |
| | Met ³⁶ | 130.8 | -0.4 | Pro ⁶³ | 97.0 | -0.1 |
| | Asn ³⁷ | 115.0 | 0.9 | Val ⁶⁴ | 99.4 | 0.3 |
| 10 | Leu ³⁸ | 112.4 | -0.8 | Glu ⁶⁵ | 128.6 | -0.5 |
| | Pro ³⁹ | 97.9 | 0.8 | Ile ⁶⁶ | 113.3 | 0.1 |
| | Gly ⁴⁰ | 56.1 | -0.9 | Aba ⁶⁷ | 84.9 | -0.2 |
| | Lys ⁴¹ | 128.1 | 0.0 | Gly ⁶⁸ | 57.0 | 0.0 |
| | Trp ⁴² | 186.4 | 0.2 | His ⁶⁹ | 137.3 | 0.2 |
| 15 | Lys ⁴³ | 128.2 | 0.0 | Lys ⁷⁰ | 127.8 | -0.4 |
| | Pro ⁴⁴ | 97.1 | 0.0 | Ala ⁷¹ | 71.4 | 0.3 |
| | Lys ⁴⁵ | 128.0 | -0.2 | Ile ⁷² | 113.4 | 0.2 |
| | Met ⁴⁶ | 131.9 | 0.7 | Gly ⁷³ | 56.8 | -0.2 |
| | Ile ⁴⁷ | 112.6 | -0.6 | Thr ⁷⁴ | 101.1 | 0.0 |
| 20 | Gly ⁴⁸ | 57.9 | 0.9 | Val ⁷⁵ | 99.2 | 0.1 |
| | Gly ⁴⁹ | 56.3 | -0.7 | Leu ⁷⁶ | 113.1 | -0.1 |
| | Ile ⁵⁰ | 112.4 | -0.8 | Val ⁷⁷ | 99.1 | 0.0 |
| | Gly ⁵¹ | 57.6 | 0.6 | Gly ⁷⁸ | 57.1 | 0.1 |
| | Gly ⁵² | 57.5 | 0.5 | Pro ⁷⁹ | 97.2 | 0.1 |
| 25 | Phe ⁵³ | 147.3 | 0.1 | Thr ⁸⁰ | 101.1 | 0.0 |
| | Ile ⁵⁴ | 112.5 | -0.7 | Pro ⁸¹ | 97.1 | 0.0 |
| | Lys ⁵⁵ | 128.9 | 0.8 | Val ⁸² | 99.2 | 0.1 |
| | Val ⁵⁶ | 99.0 | -0.1 | Asn ⁸³ | 113.8 | -0.3 |
| | Arg ⁵⁷ | 156.2 | 0.0 | Ile ⁸⁴ | 113.4 | 0.2 |
| 30 | Gln ⁵⁸ | 128.4 | 0.3 | Ile ⁸⁵ | 113.1 | 0.0 |
| | Tyr ⁵⁹ | 162.6 | -0.6 | Gly ⁸⁶ | 57.1 | 0.0 |

In addition, terminated by-products (where the peptide chain has become blocked and does not grow anymore) are present in every peptide-resin sample taken after the step in which the block occurred. Thus, there is an amplification factor equal to the number of resin samples in the batch after the point of termination. This can be seen in Fig. 10 (samples #66-33) which contains a peak at 3339.0. This corresponds to the peptide 71-99, 3242.9 (N-terminal His71) plus 96.1 dalton. The characteristics mass, together with knowledge of the chemistry used in the synthesis identifies the blocking group as CF₃CO-(97.1-H = 96.1 dalton). The observed by product is the trifluoroacetyl-peptide, N^α-Tfa-(71-99). The ratio of the amount of this component to the average amount of the other components is about 2:1. There were 34 samples combined in this sample. Thus, the terminated byproduct N^α-Tfa-(71-99) had occurred at a level of about 5mol%. This side reaction, specific to the N-terminal His-peptide chain, has not previously been reported. This illustrates the important sensitivity advantage provided by this amplification effect in detecting terminated peptides. Such byproducts are not readily detected by any other means.

Example 3Boc/Fmoc Terminations

Synthesis of the peptide LRRAFGLIGNNPLMAR-amide was performed manually on a 0.2 mmol scale using p-methylbenzhydrylamine resin and 0.8 mmoles amino acid (95 mol% N- α -Boc, 5 mol% N- α -Fmoc) according to the in situ neutralization methods of Schnolzer et al (9). The following side chain protecting groups were used: Boc-Arg, tosyl; Fmoc-Arg, 2,3,6-trimethyl-4-methoxybenzenesulfonyl (Mtr). Fmoc-Arg(Mtr) was used for its greater stability in trifluoroacetic acid (TFA). After completion of the chain assembly, Fmoc groups were removed using 50% piperidine/DMF, followed by Boc group removal in TFA. The peptide fragments were then cleaved from the resin by treatment with HF-10% p-cresol (0°C, 1 hour). The resulting crude peptide products were precipitated and washed with ether, dissolved in 50% acetic acid, diluted with water and lyophilized. The mass spectra of the reaction mixture thus produced is shown in Fig. 11.

Example 4

Post-ninhydrin Experiment The machine-assisted assembly of the peptide LRRASGLIYNNPLMAR-amide was performed according to the in situ neutralization methods of Schnolzer and Kent (9) on a 0.25 mmol scale using MBHA resin and 2.2 mmol N- α -Boc amino acids. The following side chain protecting groups were used: Arg, tosyl; Asn, xanthyl; Ser, benzyl(Bzl); Tyr, bromobenzyloxycarbonyl(BrZ). Resin samples were collected at each step in the synthesis and each sample was individually subjected to the quantitative ninhydrin reaction. These samples were then pooled and the Boc groups removed in neat TFA. Cleavage of the peptide fragments from the resin was performed by treatment with HF-10% p-cresol (OC, 1 hour). The resulting crude peptide products were precipitated and washed with ether, dissolved in 50% acetic acid, diluted with water and lyophilized. The mass spectrum of the mixture is shown in Fig. 15.

CITATIONS

The following publications are referred to in this specifications. The complete disclosure of each of them is hereby incorporated by references.

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5. A. Tsugita, K. Takamoto, M. Kamo, H. Iwadate, Eur. J. Biochem. 206, 691 (1992)
6. G.E. Tarr (1977), in Methods Enzymology 47, 355.
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8. S.B.H. Kent, Annual Rev. Biochem. 57, 957-984 (1988)
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10. W.A. Schroeder, Meth. Enzymol. 25, 298 (1972)

WHAT IS CLAIMED IS:

1. A process for the sequence analysis of a formed or forming polypeptide which comprises the steps of producing a reaction mixture containing a peptide ladder comprising a series of adjacent polypeptides in which each member of the series differs from the next adjacent member by one amino acid residue and thereafter determining the differences in molecular mass between adjacent members of the series by mass spectroscopy, such differences coupled with the positions of said adjacent members in the series being indicative of the identity and position of the said amino acid residue in the formed or forming peptide.

2. The process of claim 1 wherein a plurality of peptide ladders are produced from separate formed polypeptides in the same reaction zone.

3. The process of claim 1 wherein a plurality of peptide ladders are produced from separate formed polypeptides in separate reaction zones.

4. The process of claim 2 or 3 wherein the polypeptide is absorbed on a membrane support.

5. The process of claim 1 wherein the formed polypeptide is a modified polypeptide.

6. The process of claim 5 wherein the polypeptide is phosphorylated.

5 7. The process of claim 5 wherein the polypeptide includes a phosphorylated serine residue.

8. A process for the sequence analysis of a formed polypeptide which comprises the steps of:

10 a: reacting the polypeptide with a molar excess of a pair of reagents comprising a coupling reagent and a terminating reagent each of which forms a reaction product with a terminal amino acid residue of the polypeptide to be analyzed under the same reaction conditions; the reaction product formed
15 between the terminating reagent and the terminal amino acid residue of the polypeptide being stable under all subsequent reaction conditions; the reaction product formed between the coupling reagent and terminal amino acid residue of the
20 polypeptide to be analyzed being removable as a cleavage product from the original polypeptide together with the terminal amino acid to which it is attached by changing the reaction conditions;

b: changing the reaction conditions so that the cleavage product separates, thereby to form a reaction mixture comprising:

i. unreacted coupling and terminating reagents.

ii. a first reaction product which is the reaction product between the original polypeptide and the terminating reagent,

iii. a newly formed polypeptide from which the terminal amino acid residue has been removed;

c: repeating steps a and b any selected number of cycles thereby to form a final mixture which comprises:

i. reaction product between the original polypeptide and the terminating reagent,

ii. a peptide ladder which is series of adjacent reaction products each member of which is formed by reaction between the terminating reagent and the terminal amino acid residue of a fraction of the newly formed polypeptide of each cycle, the number of such reaction products, including said first reaction product, being equal to the number of cycles conducted; and

d: determining the differences in molecular mass between adjacent members of the series of reaction products by mass spectroscopy, such differences being equal to the molecular mass of the amino acid residue cleaved from the original polypeptide and from each subsequent polypeptide of the series, such differences coupled with the positions of said adjacent members in the mass spectrum being indicative of the identity and position of that amino acid residue in the original polypeptide.

9. The process of claim 8 wherein the coupling and terminating reagents react with the terminal amino acid at the amino terminal of the original polypeptide.

10. The process of claim 9 wherein the coupling reagent is phenyl isothiocyanate and the terminating reagent is phenyl isocyanate.

11. The process of claim 8 wherein the coupling and terminating reagents react with the terminal amino acid at the carboxy end of the original polypeptide.

12. A process as in claim 8, 9, 10 or 11 wherein at least two different polypeptides are simultaneously analyzed in the same reaction mixture.

13. The process of claim 8, 9, 10 or 11 wherein a plurality of peptide ladders are produced from separately formed polypeptides in the same reaction zone.

14. The process of claim 8, 9, 10 or 11 wherein a plurality of peptide ladders are produced from separately formed polypeptides in separate reaction zones.

15. The process of claim 13 wherein the polypeptide is absorbed on a membrane support.

16. The process of claim 14 wherein the polypeptides are absorbed on resin supports.

17. The process of claim 8, 9, 10 or 11 wherein the formed polypeptide is a modified polypeptide.

18. The process of claim 8, 9, 10 or 11 wherein the formed polypeptide is a modified polypeptide which is modified by phosphorylation.

19. The process of claim 8, 9, 10 or 11 wherein the formed polypeptide is a modified polypeptide which is modified by the presence of a phosphorylated serine residue.

20. A process for the sequence analysis of a formed polypeptide which comprises the steps of:

a: reacting the polypeptide with a coupling reagent under conditions such that the terminal amino acid residue of only a portion of the polypeptide to be analyzed reacts with the coupling reagent, the reaction product formed between the coupling reagent and the terminal amino acid of the polypeptide to be analyzed being removable as a cleavage product from the original polypeptide together with the terminal amino acid to which it is attached by changing reaction conditions;

b: changing the reaction conditions so that the cleavage product separates, thereby to form a reaction mixture comprising:

- i. unreacted coupling agent
- ii. the cleavage product
- iii. unreacted original formed polypeptide
- iv. a newly formed polypeptide with one less amino acid residue than the original polypeptide

c: repeating steps a and b any selected number of cycles thereby to form a final mixture which comprises a series of adjacent polypeptides adjacent members of which differ by one amino acid residue; and

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d: determining the differences in molecular mass between adjacent members of the series of mass spectroscopy, such differences being equal to the mass of the amino acid residue cleaved from the original polypeptide and from each subsequently formed polypeptide of the series, such differences coupled with the position of said adjacent members in the mass spectrum being indicative of the identity and position of that amino acid residue in the original polypeptide.

21. The process of claim 20 wherein the coupling reagent reacts with the terminal amino acid at the amino terminal of the original polypeptide.

22. The process of claim 21 wherein the coupling reagent is phenyl isothiocyanate.

23. The process of claim 20 wherein the coupling reagent reacts with the terminal amino acid at the carboxy end of the original polypeptide.

24. The process of claim 20, 21, 22 or 23 wherein at least two different polypeptides are simultaneously analyzed in the same reaction mixture.

25. The process of claim 20, 21, 22, or 23 wherein a plurality of peptide ladders are produced from separate formed polypeptides in the same reaction zone.

5 26. The process of claim 20, 21, 22, or 23 wherein a plurality of peptide ladders are produced from separate formed polypeptides in separate reaction zones.

27. The process of claim 25 wherein the polypeptide is absorbed on a membrane support.

10 28. The process of claim 26 wherein the polypeptides are absorbed on resin supports.

29. The process of claim 20, 21, 22 or 23 wherein the formed polypeptide is a modified polypeptide.

15 30. The process of claim 20, 21, 22 or 23 wherein the formed polypeptide is a modified polypeptide which is modified by phosphorylation.

31. The process of claim 20, 21, 22 or 23 wherein the formed polypeptide is a modified polypeptide which is modified by the presence of a phosphorylated serine residue.

32. A process for the sequence analysis of a forming polypeptide which is being formed by cyclical, coupling and deblocking of N^{α} -blocked amino acid residues to form a final polypeptide one terminal of which is bound to a support which process comprises collecting a support bound sample after each cycle, mixing the collected samples, cleaving from the support in the collected samples, the polypeptides formed thereon to produce a reaction mixture containing a peptide ladder comprising a series of adjacent polypeptides in which each member of the series differs from the next adjacent member by one amino acid residue and thereafter determining the differences in molecular mass between adjacent members of the series by mass spectroscopy, such differences coupled with the positions of said adjacent members in the series being indicative of the identity and position of the said amino acid residue in the formed or forming peptide.

33. A process for the sequence analysis of a forming polypeptide which is being formed by cyclical coupling and deblocking of N^{α} -blocked amino acid residues to form a final polypeptide one terminal of which is bound to a support which process comprises:

a. Conducting the coupling step of each cycle with a mixture of the same amino acid residue the major portion of which is blocked with a blocking group removable under selected reaction conditions, the minor portion of which is blocked with a blocking group which is stable under the said reaction conditions,

b. Conducting each deblocking step of each cycle under conditions such that the removable blocking group is removed,

c. Repeating steps a and b, and

d. Removing the products from the support to obtain a mixture containing a peptide ladder comprising a series of adjacent polypeptides in which each member of the series differs from the next adjacent member by one amino acid residue and thereafter determining the differences in molecular mass between adjacent members of the series by mass spectroscopy, such differences coupled with the positions of said adjacent members in the series being indicative of the identity and position of the said amino acid residue in the formed or forming peptide

1-2-3-4-5-6-7-8-9-.....-n-(OH)

INTACT STARTING
PEPTIDE CHAIN

(X)-1-2-3-4-5-6-7-8-9-.....-n-(OH)

(X)-2-3-4-5-6-7-8-9-.....-n-(OH)

(X)-3-4-5-6-7-8-9-.....-n-(OH)

(X)-4-5-6-7-8-9-.....-n-(OH)

(X)-5-6-7-8-9-.....-n-(OH)

etc.

FIG.1

SUBSTITUTE SHEET

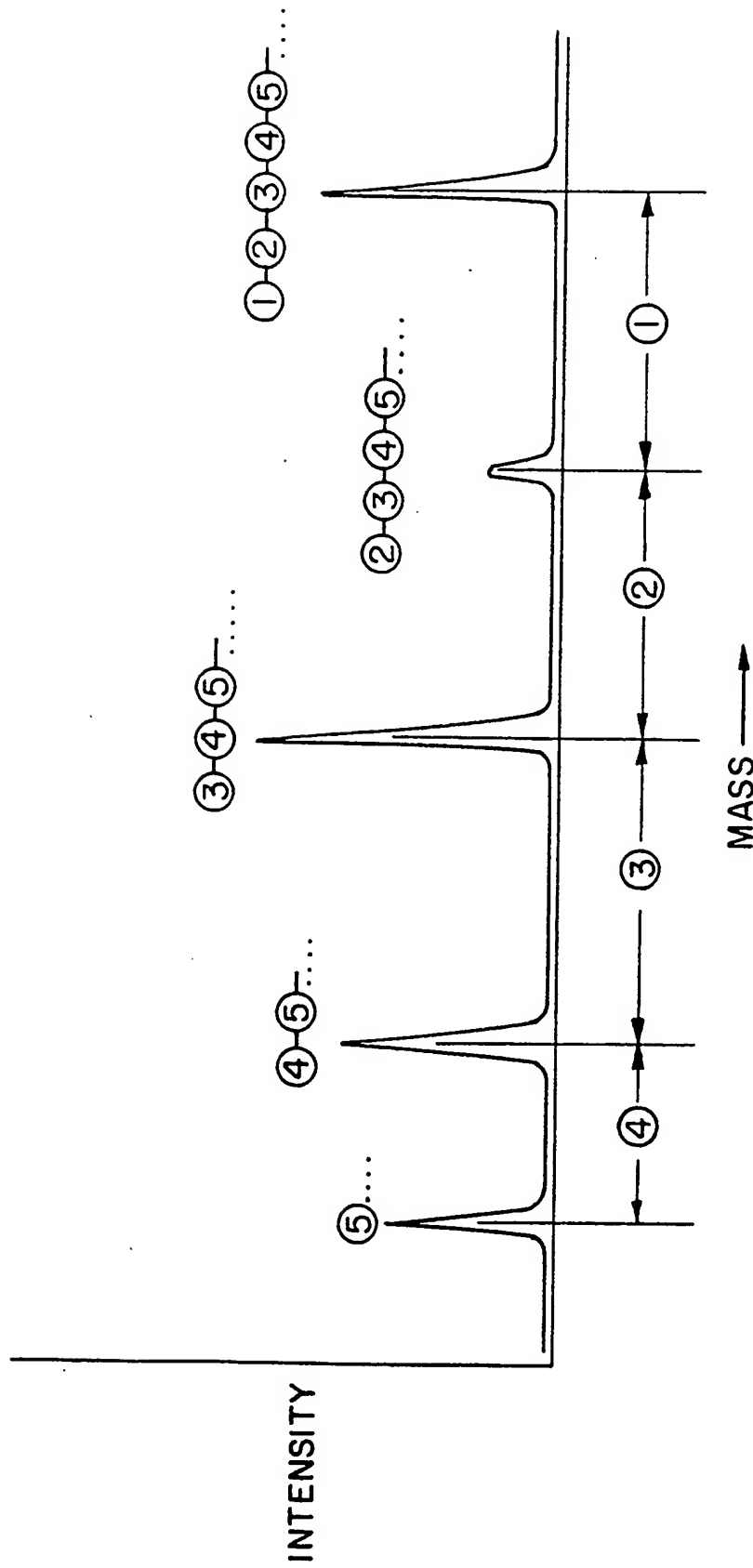


FIG. 2

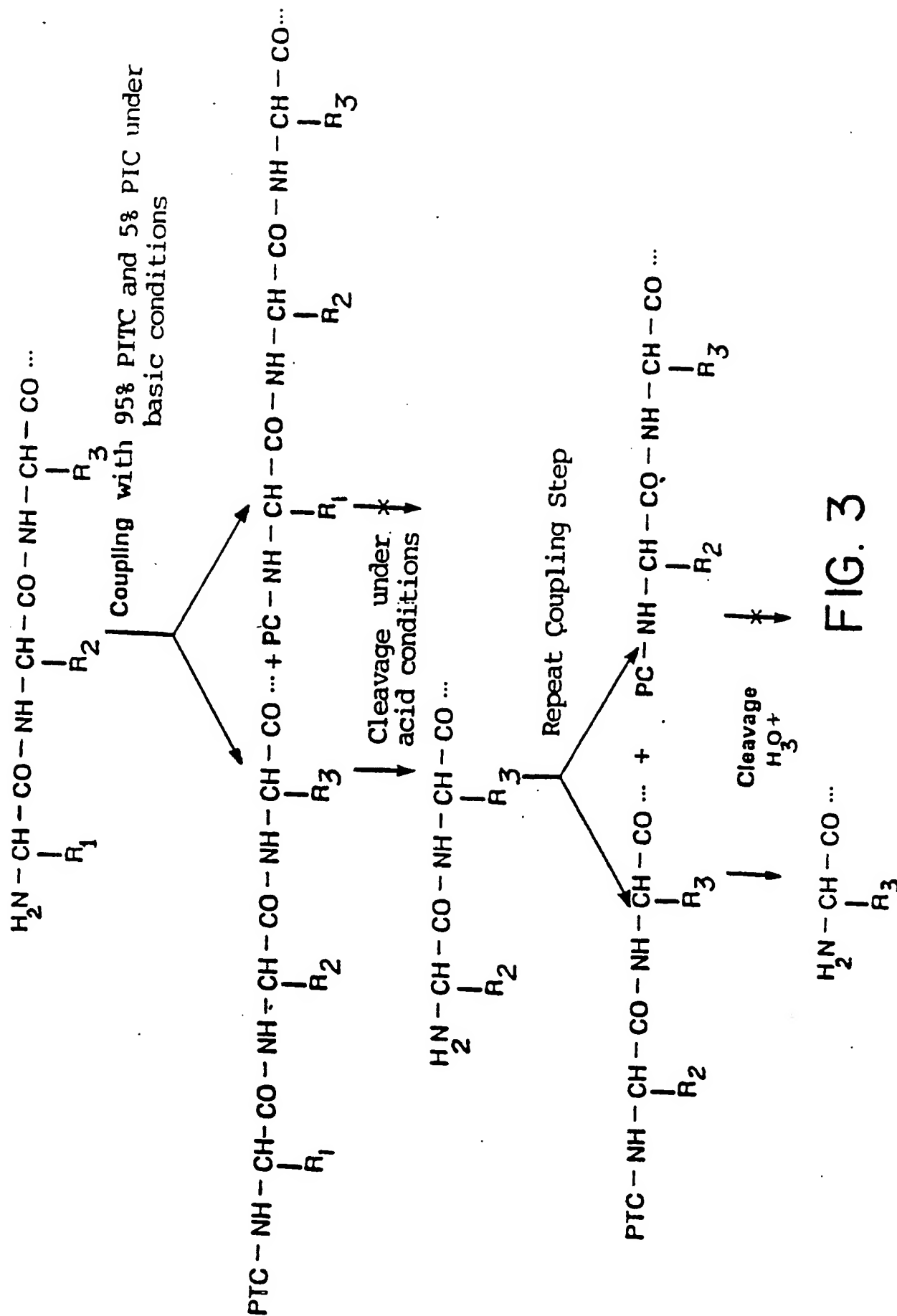


FIG. 3

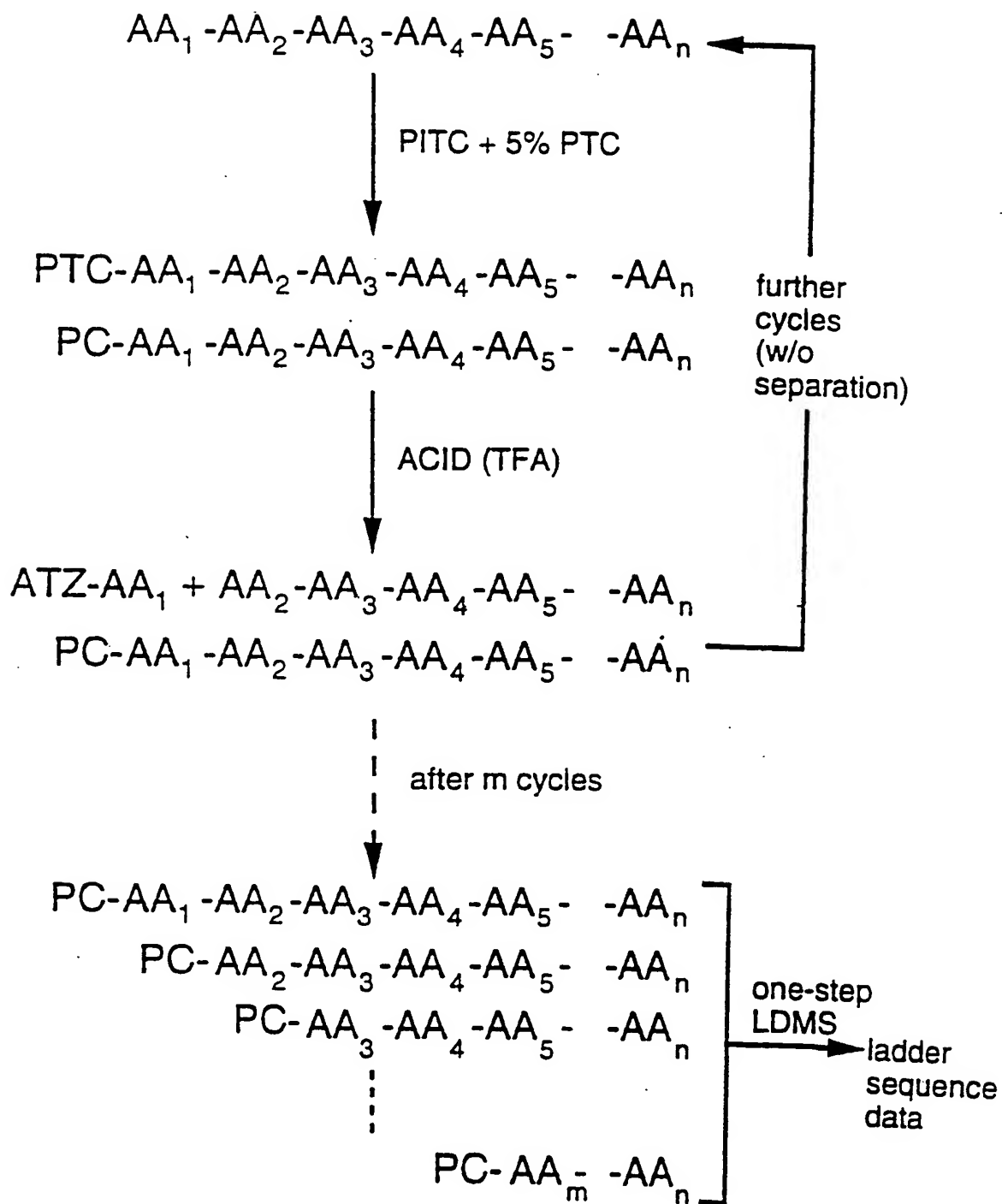
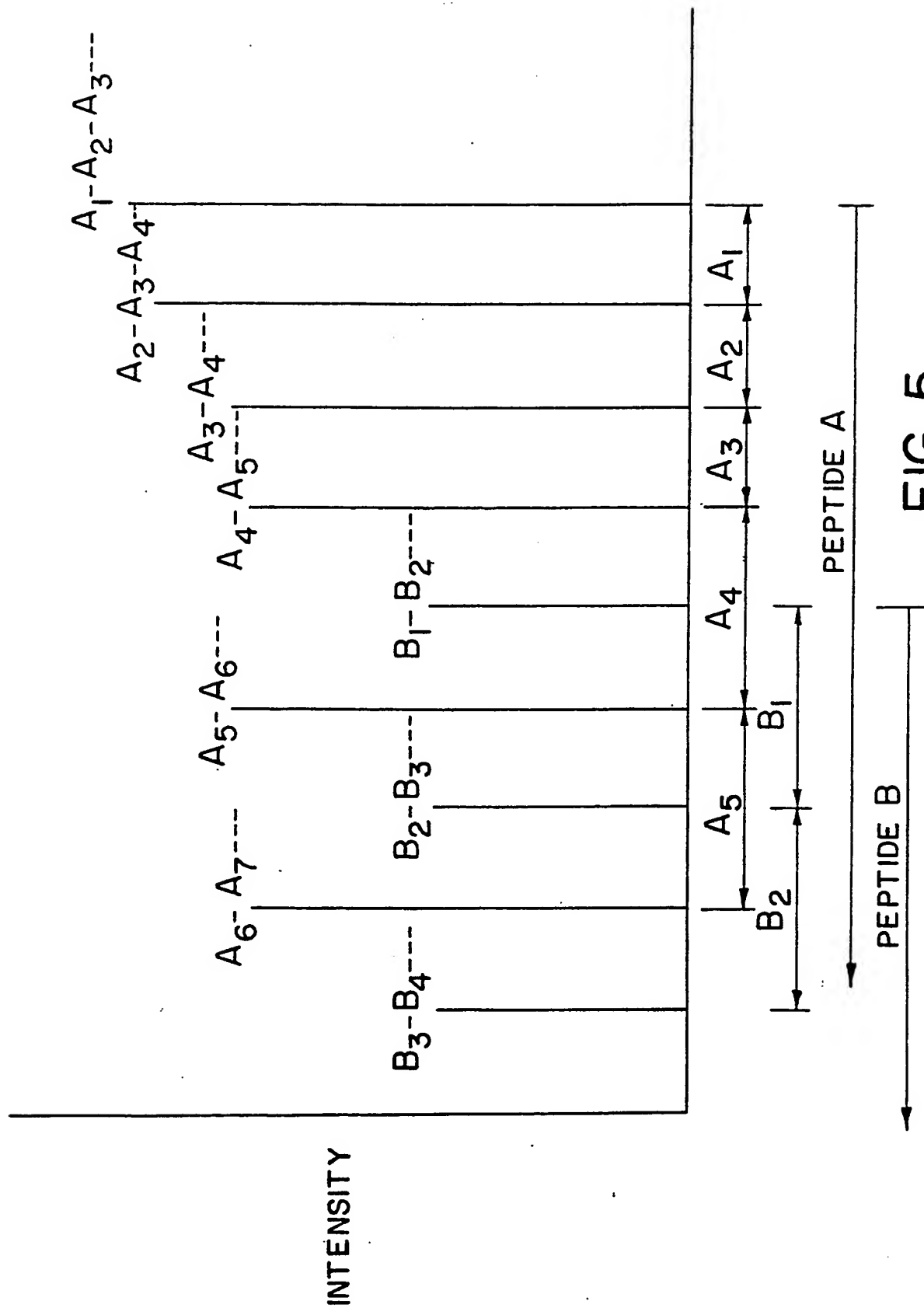


FIG.4



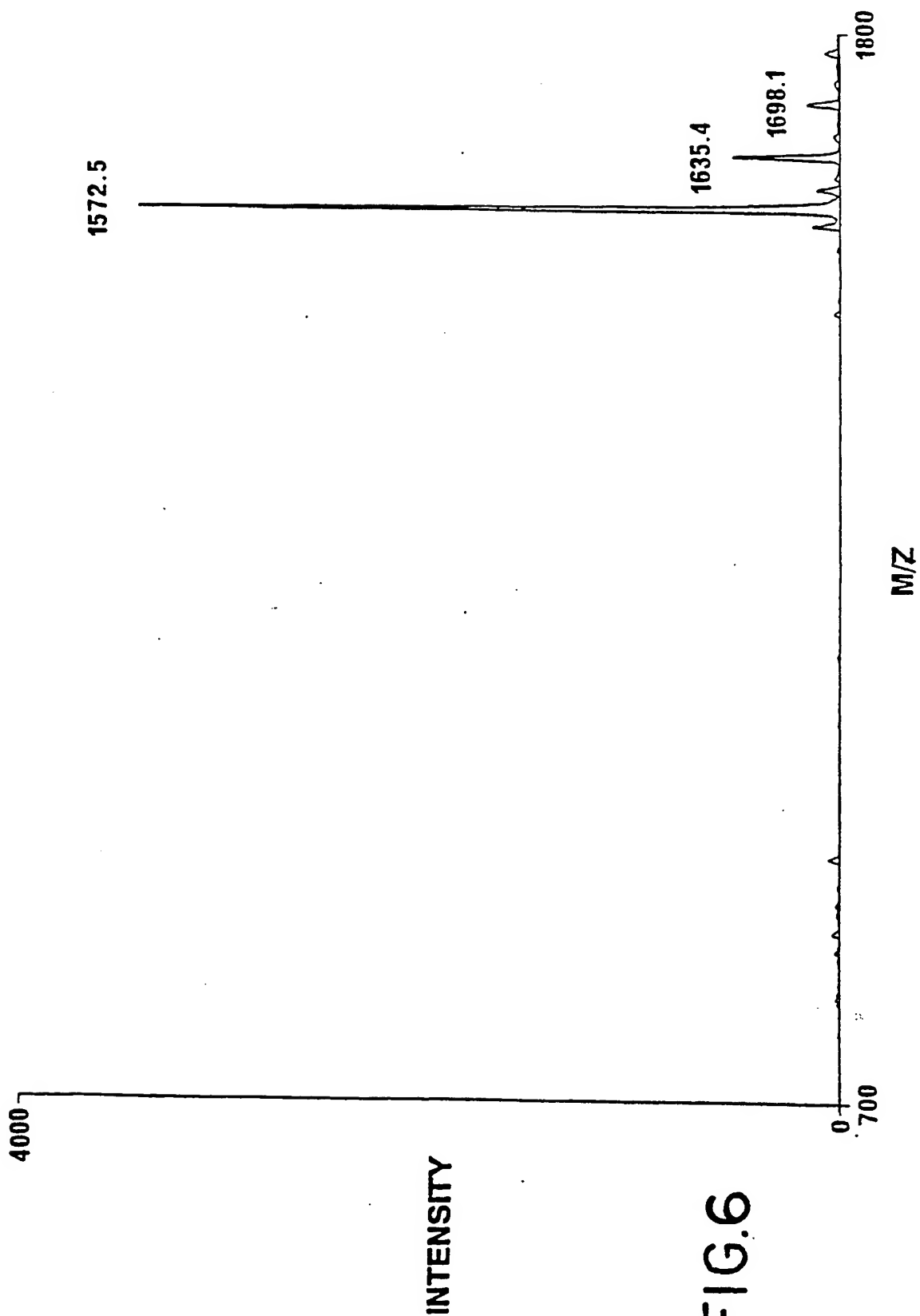


FIG.6

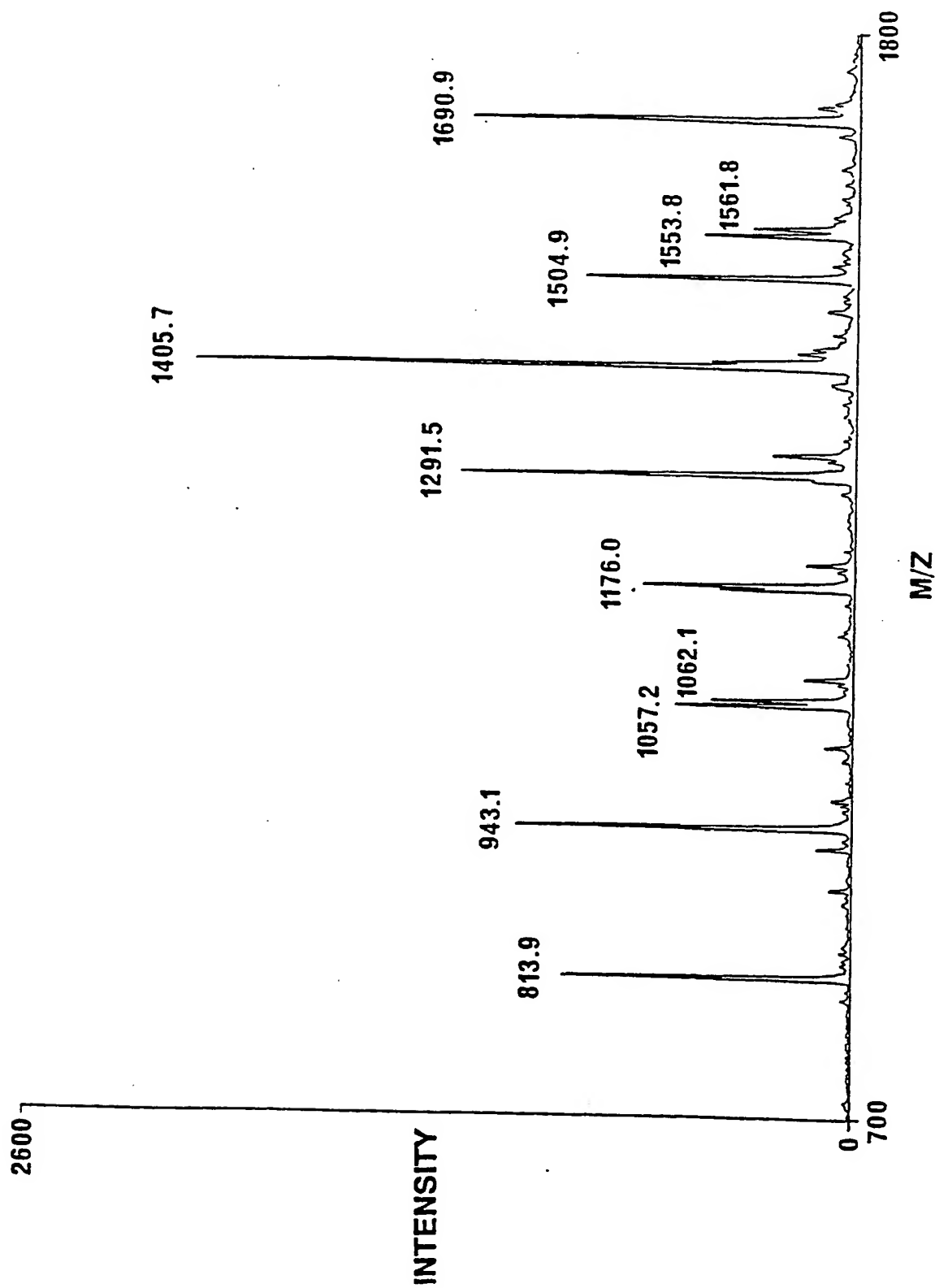


FIG.7

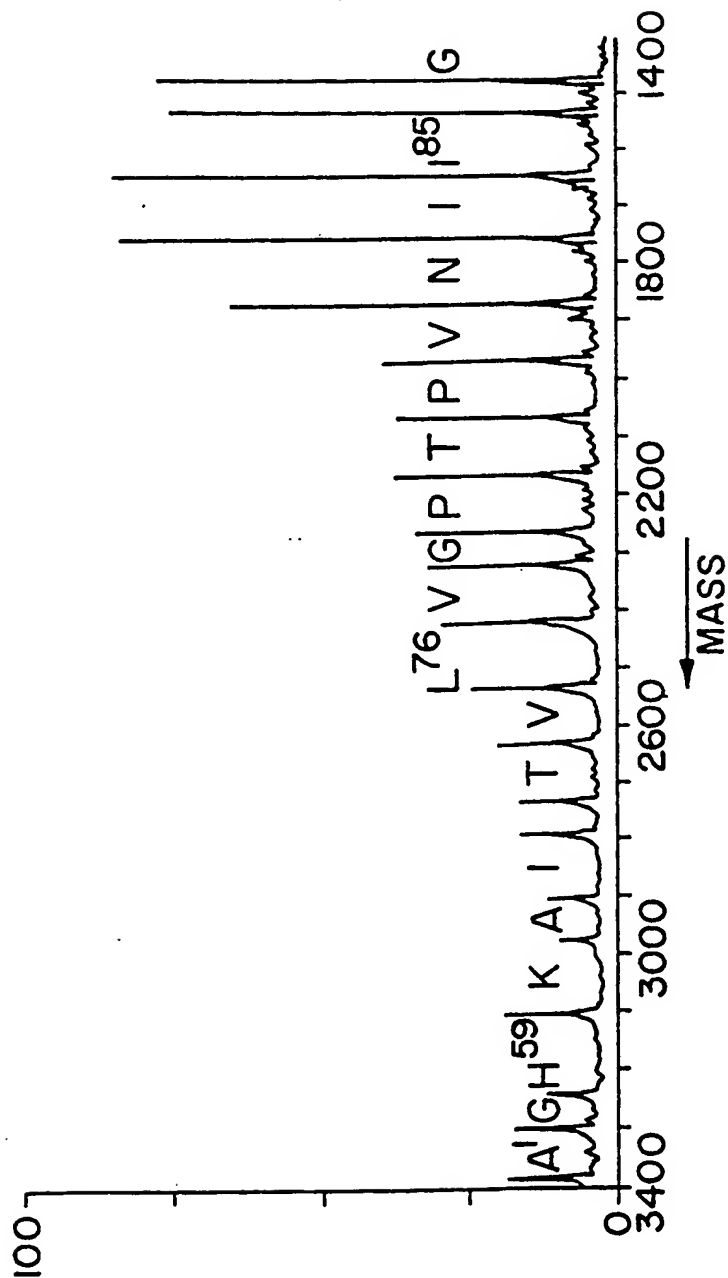


FIG. 8

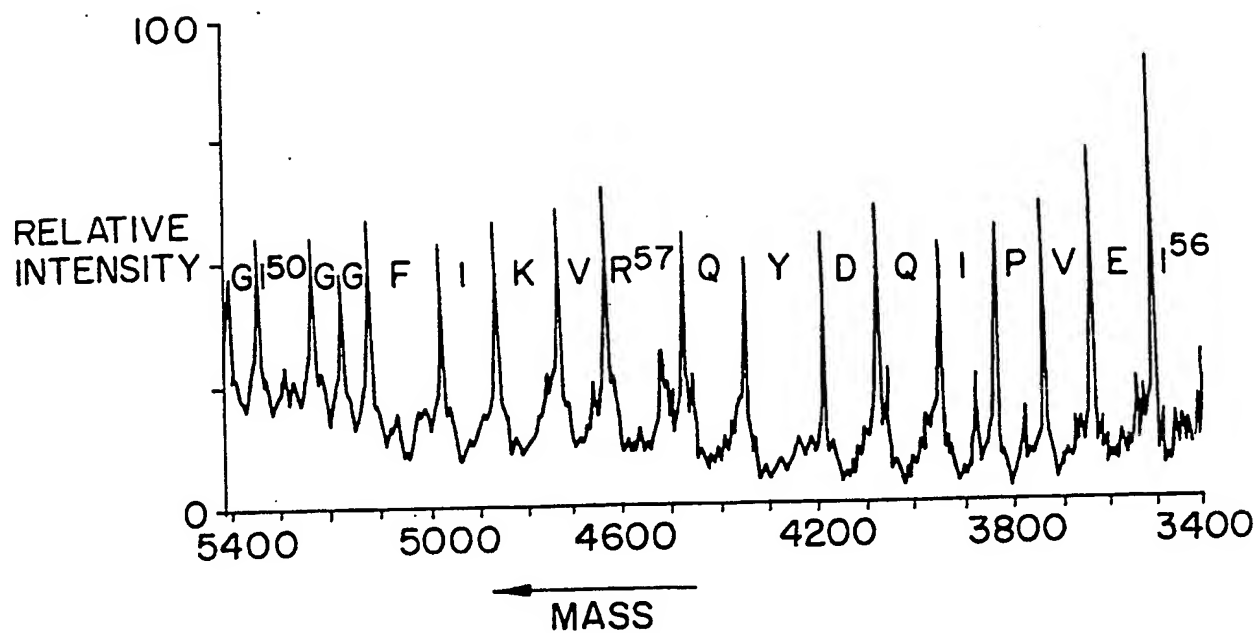


FIG. 9a

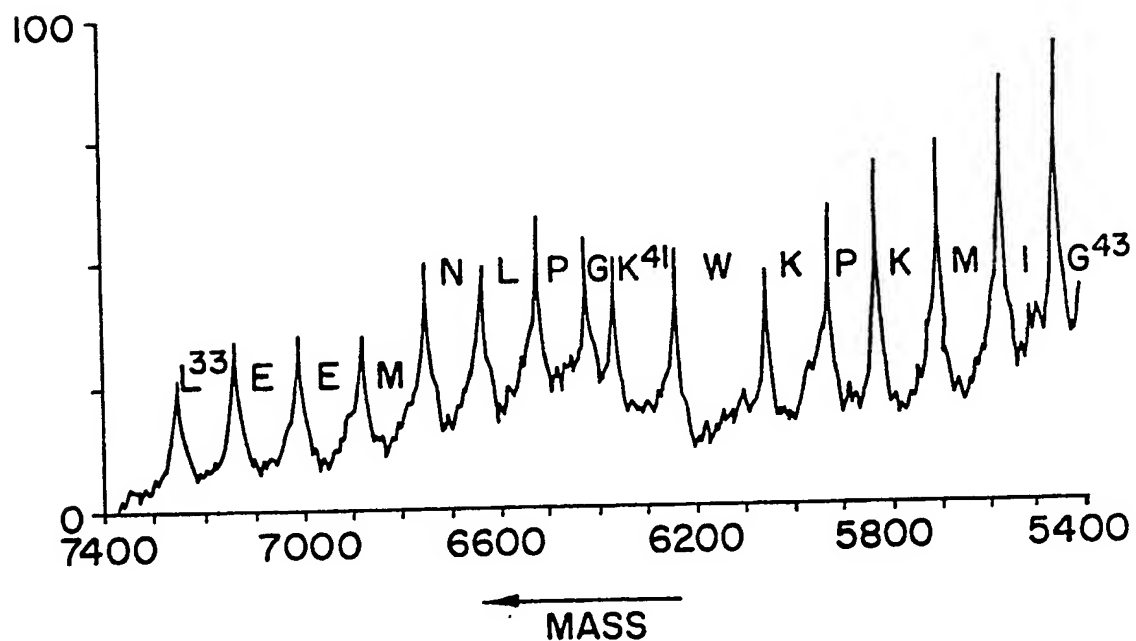


FIG. 9b

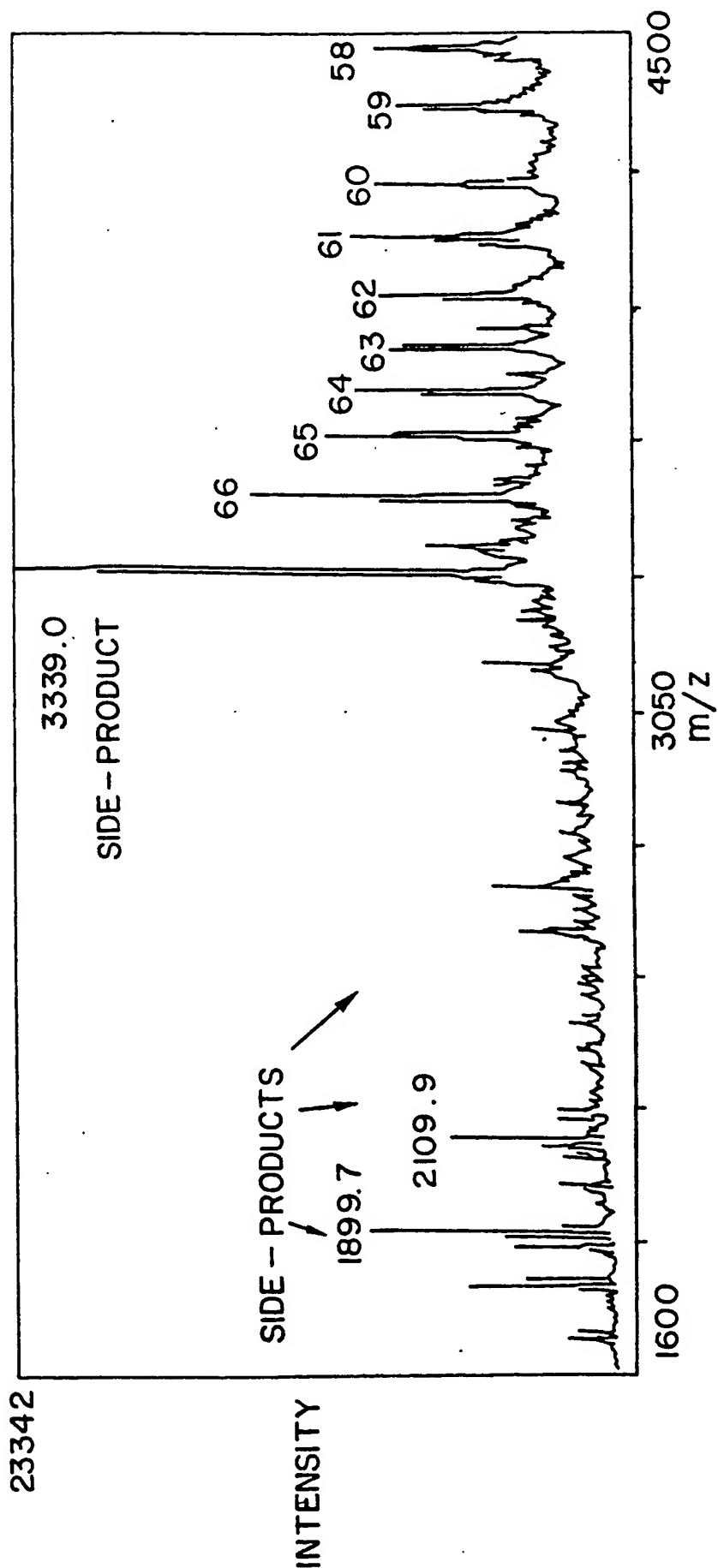


FIG. 10

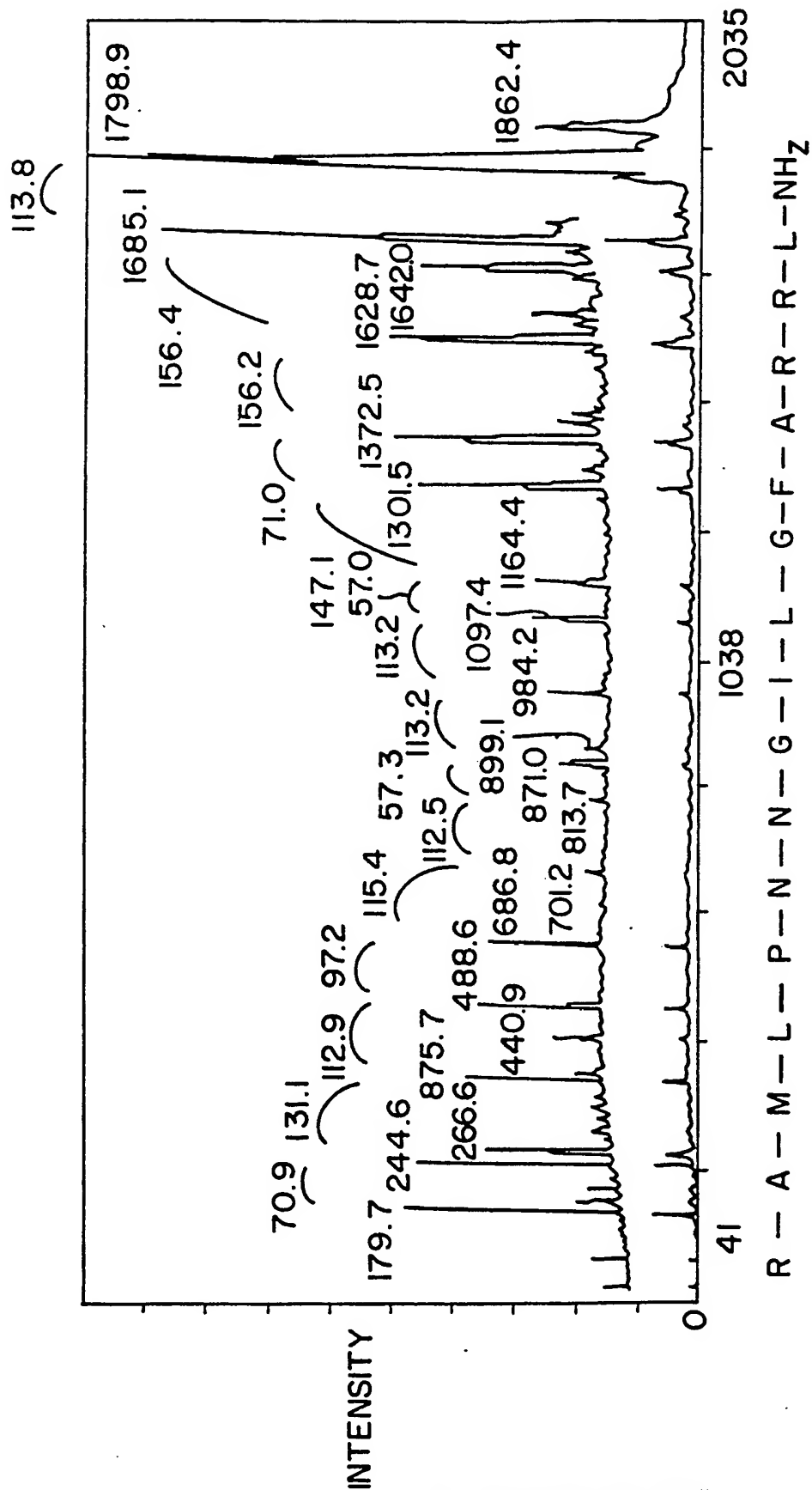


FIG. 11

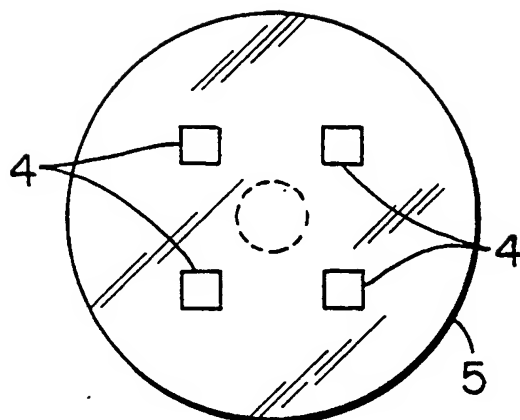


FIG. 12A

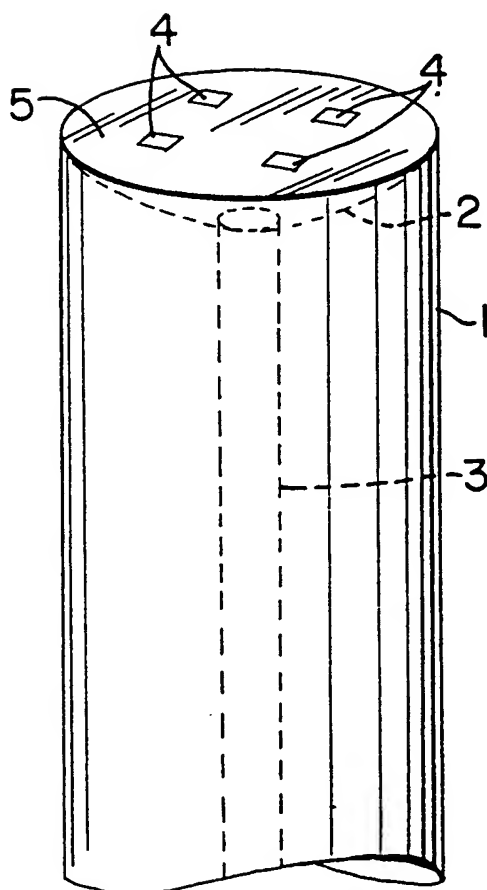


FIG. 12B

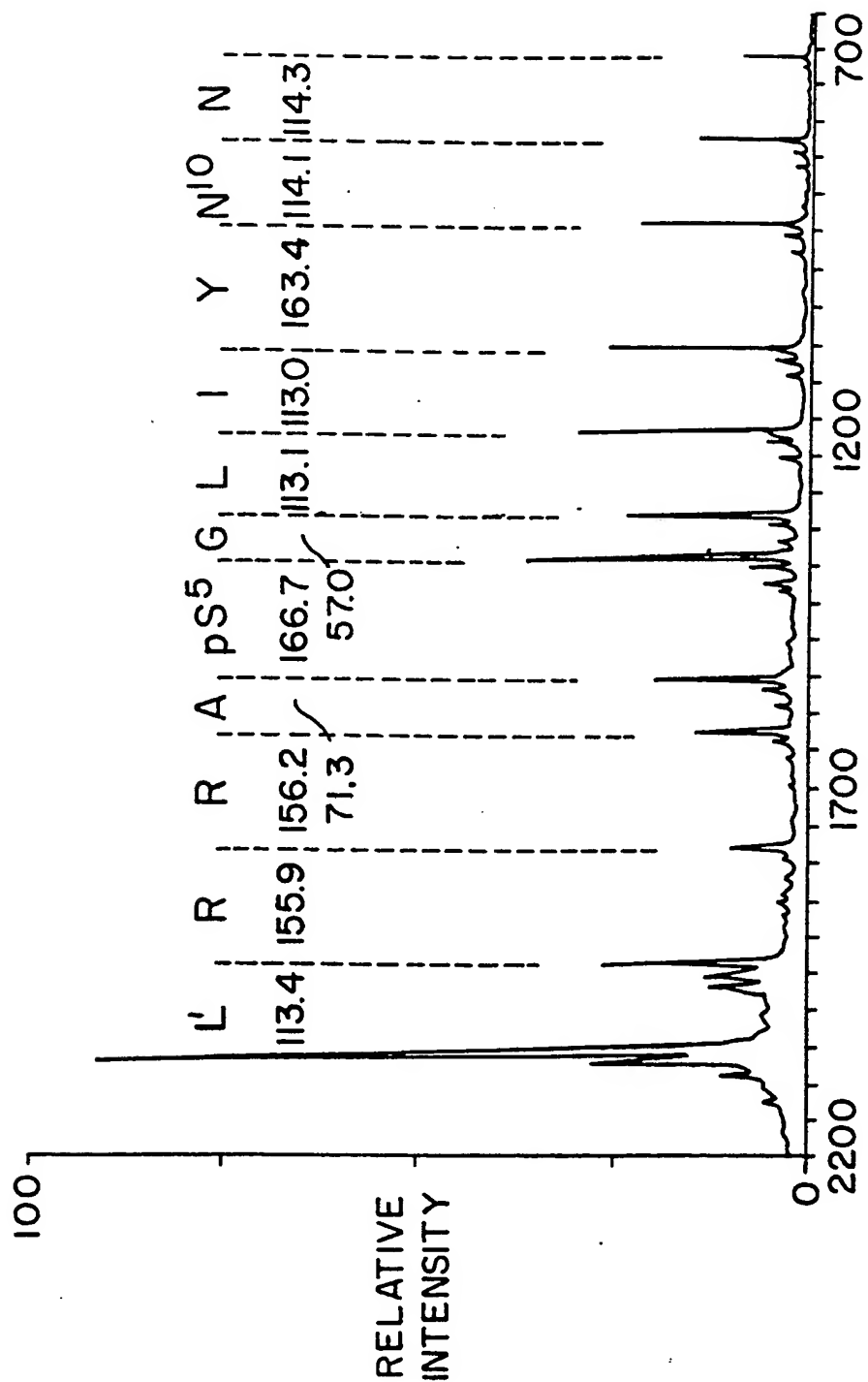


FIG. 13A

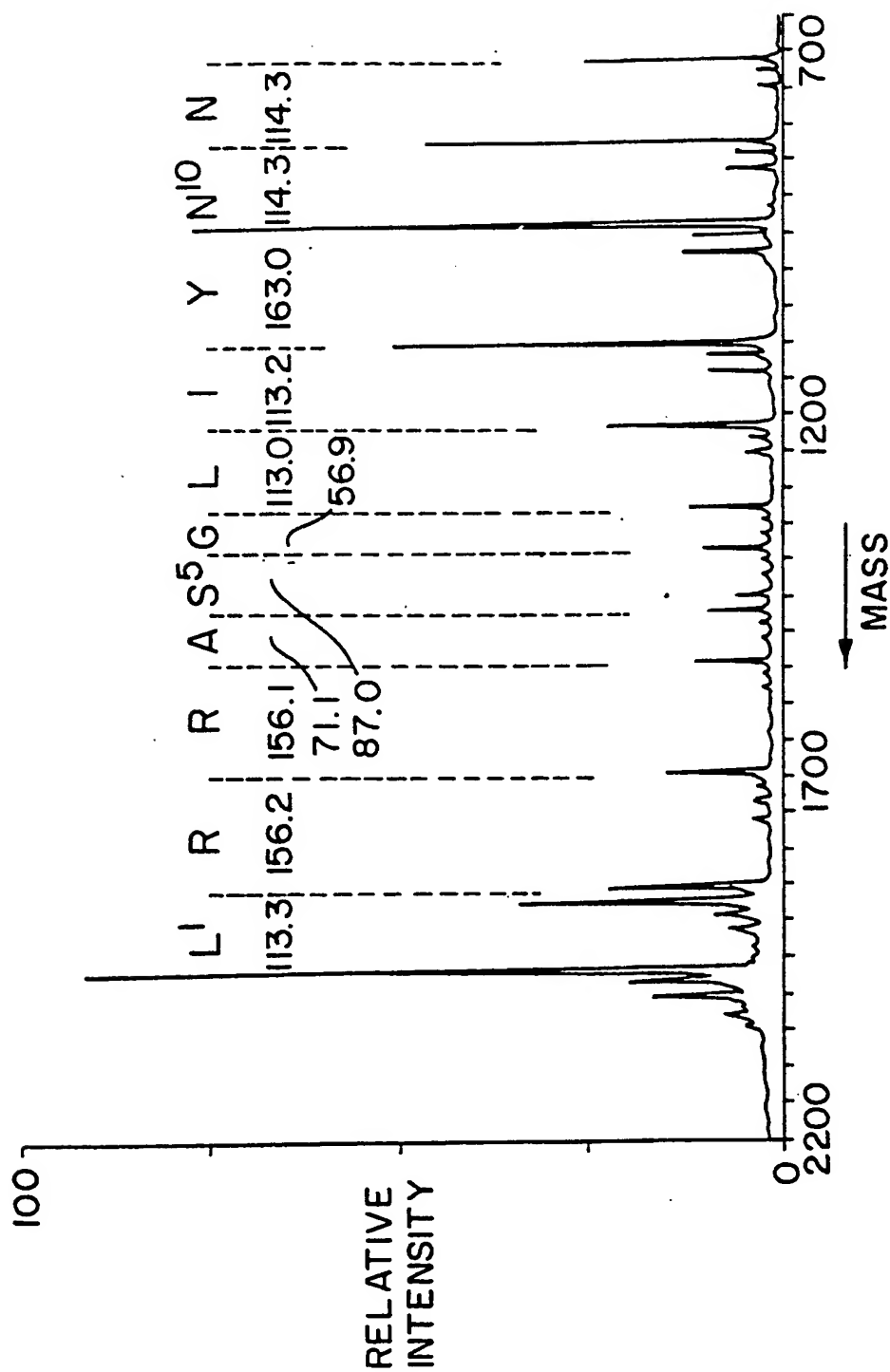


FIG. 13B

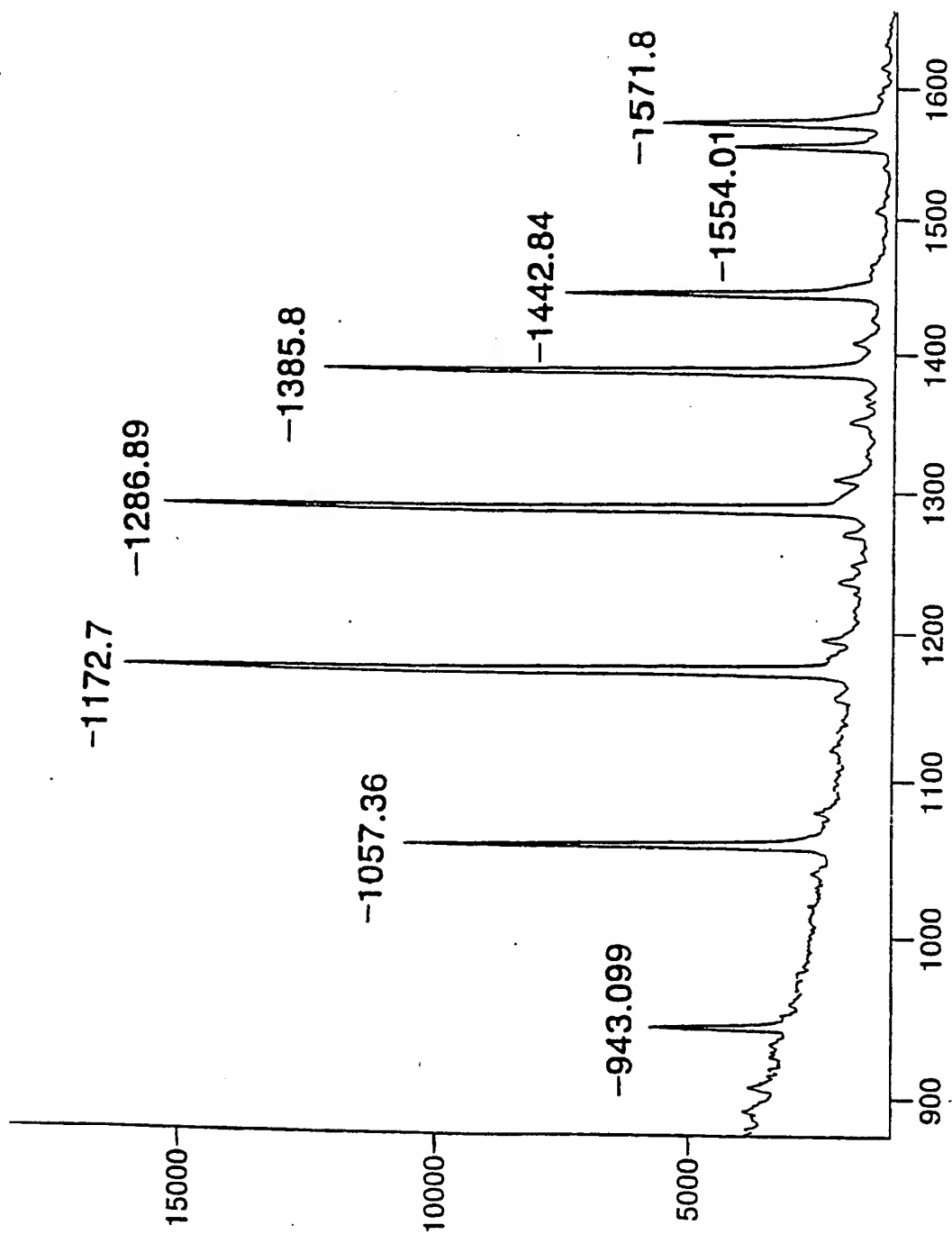


FIG.14

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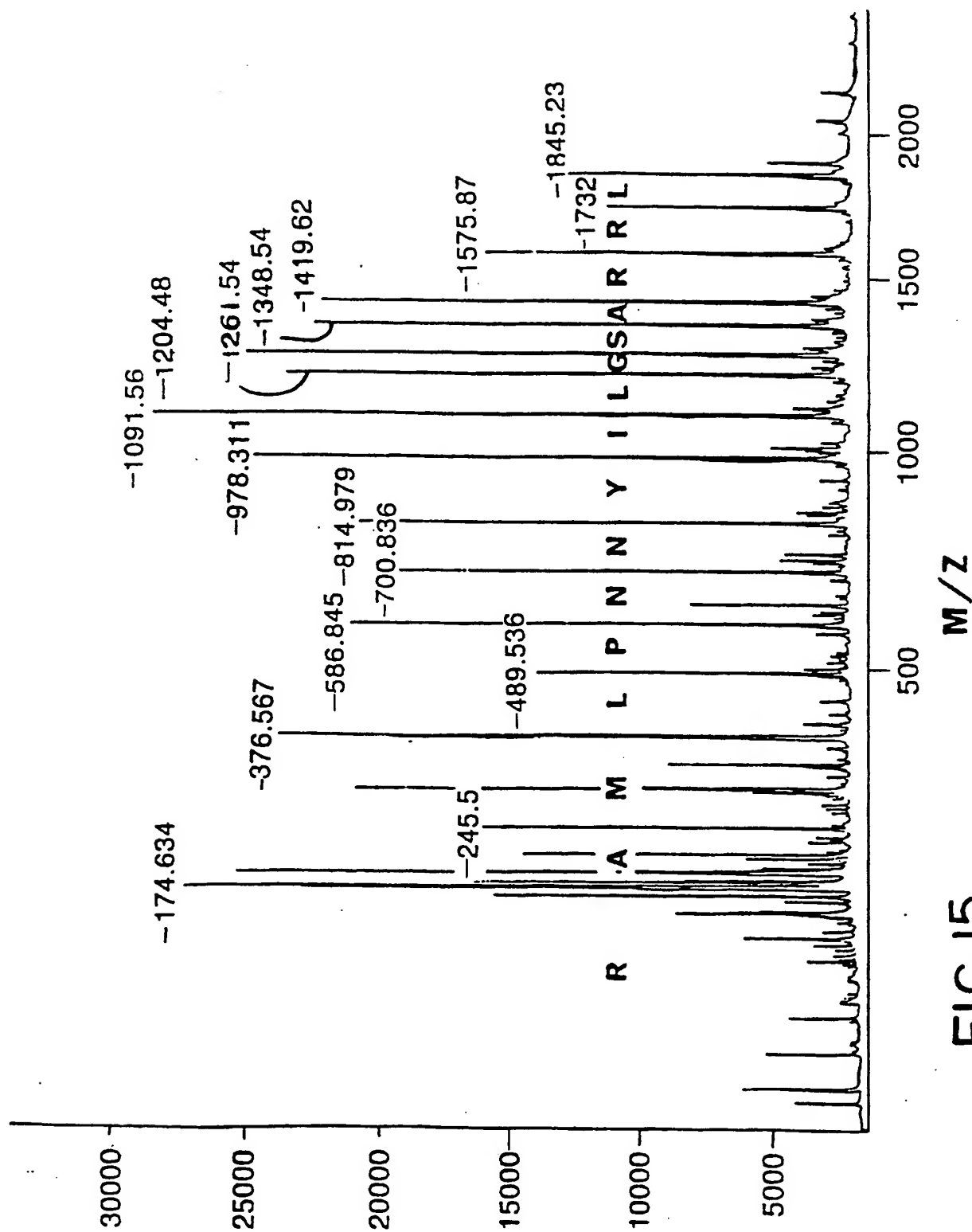


FIG.15

SUBSTITUTE SHEET

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) : G01N 33/44

US CL : 436/89

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 436/89

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, DIALOG

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|---|-----------------------|
| Y | Protein Science, Vol. 1, issued January 1992, Ruedi Aebersold et al., "Design, Synthesis, and characterization of a protein sequencing reagent yielding amino acid derivatives with enhanced detectability by mass spectrometry", page 494-503, see entire article. | 1-33 |
| Y | Biomedical Mass Spectrometry, Vol. 10, No.2, issued 1983, R. Self et al., "The combined use of enzymatic hydrolysis and fast atom bombardment mass spectrometry for peptide sequencing", page 78-82, see entire article. | 1-33 |

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

| | | |
|---|-----|--|
| * Special categories of cited documents: | *T | later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention |
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| *E* earlier document published on or after the international filing date | *Y* | document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art |
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| *O* document referring to an oral disclosure, use, exhibition or other means | | |
| *P* document published prior to the international filing date but later than the priority date claimed | | |

Date of the actual completion of the international search

13 July 1993

Date of mailing of the international search report

24 AUG 1993

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 Washington, D.C. 20231

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GARY L. BROWN

Telephone No. (703) 308-0196

| C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT | | |
|---|--|-----------------------|
| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
| Y | Methods In Enzymol, Vol. 25, issued 1972, William Konigsberg, "Subtractive Edman Degradation", page 326-333, see entire article. | 1-33 |
| Y | Methods In Enzymol., Vol. 25, issued 1972, Frank F. Richards et al., "Mass Spectroscopy of Methylthiohydantoin Amino Acids: Identification, Quantitation, and the Analysis of Mixtures", page 314-226, see entire article. | 1-33 |
| Y | Methods In Enzymol., Vol. 25, issued 1972, Walter A. Schroeder, "Degradation of Peptides by the Edman Method with Direct Identification of the Phenylthiohydantoin-Amino Acid", page 298-314, see entire article. | 1-33 |
| Y,P | Int. J. Peptide Protein Res., Vol.40, No.3/4, issued September-October 1992, Martina Schnolzer et al., "In situ Neutralization in Boc-chemistry Solid Phase Peptide Synthesis", page 180-193, see entire article. | 1-33 |
| Y,P | Eur. J. Biochem., Vol. 206, No. 3, issued 11 June 1992, Akira Tsugita et al., "C-Terminal Sequencing of Protein: A Novel Partial Acid Hydrolysis and Analysis by Mass Spectrometry", page 691-696, see entire article. | 1-33 |